ANIMAL CHEMISTRY,

OR

CHEMISTRY

IN ITS APPLICATIONS TO

PHYSIOLOGY AND PATHOLOGY.

(Justus)

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ADVERTISEMENT.

The present publication is the first part of a new and greatly enlarged edition of Baron Liebig's Animal Chemistry. It contains "the Chemical Process of Respiration and Nutrition," along with the first section of "the Metamorphoses of Animal Tissues." It will be seen by the author's preface, that this first section is entirely new, and devoted to a consideration of the method which ought to be followed, and of the principles which ought to guide us in the investigation of that important subject.

I cannot refrain from directing the attention of the reader to the very interesting and important additions made, in the present edition, to the different sections of "the Chemical process of Respiration and Nutrition;" which are such as to render it, in a great measure, a new work. Under the heads of animal heat; of the nutrition of the carnivora and herbivora; of the origin and use of the bile; of the relation between the change of matter and the consumption of oxygen; of the origin and use of the non-nitrogenized elements of food, and particularly of fat, and their relative value as sources of heat; of the effects of alcohol and fermented liquors; of the effect produced on the volume of the inspired air by the different articles of food; and lastly, of the true functions of the intestinal canal, and the origin, nature, and composition of the fæces, with their relation to the food and to the supply of oxygen; under all these heads the reader will find such an amount of new and interesting matter as must satisfy him that we have

entered on the true path of discovery, and that the industry of modern chemists has been most profitably employed during the period which has elapsed since the first edition of this work appeared.

The profound and ingenious views developed by the author in reference to the derivation from carbonic acid, in the living plant, of the fatty and other vegetable acids, of sugar, starch, gum, and woody fibre; and his very full development of the means by which the opposite process, namely, the reconversion of these matters into carbonic acid, in the living animal body, is effected, are very striking proofs of the progress which has been made, and which is due to the application of the true principles of scientific investigation. The same remark applies to the new and very important section on the origin and nature of the fæces.

Part II., completing the work, is in preparation, and will shortly appear. It has only been delayed in order to insure its containing the results of researches into the nature of the constituents of the animal body, which the progress of Chemistry has rendered necessary.

WILLIAM GREGORY.

October 10, 1846.

PREFACE.

The author has reason to congratulate himself, that the method which he has recommended, for the attainment of just conclusions in regard to the chemical processes of organic nature, has been recognized as being well adapted to the end in view.

During the four years which have elapsed since the publication of the first edition of this work, several philosophers have subjected some of the processes of the animal organism to a thorough investigation; and if, in consequence of these researches, our views have received an expression more definite and more nearly approaching the truth, this must be regarded as a proof, not that we were in error, but that we have made some progress.

By the researches of Vierordt, the relation between the number of respirations and the amount of oxygen taken up and given out in the form of carbonic acid has been ascertained; and the experiments of Dulong, published after his death, and continued by Favre and Siebermann and others, on the heat given out in the combustion of carbon and hydrogen, admit of no further doubt as to the true source of animal heat.

The author has endeavored to explain and illustrate very fully the process of the formation of carbonic acid in the body, and to direct the attention of physiologists and pathologists to the relation of mutual dependence existing between the quantity and

quality of the food, the consumption of oxygen in the respiratory process, and the amount and composition of the fæces.

In a special chapter, newly added to the work, he has made an attempt to set in a clearer light the mutual relations of Chemistry and Physics to Physiology and Pathology; and here he cannot refrain from acknowledging how great have been his obligations, in reference to this object, to the study of Mr. Mill's System of Logic (London, 2nd ed., 1846). Indeed, he feels that he can claim no other merit than that of having applied to some special cases, and carried out further than had been previously done, those principles of research in natural science which have been laid down by that distinguished philosopher.

The revision of the strictly chemical part of this work has rendered necessary a new and more accurate investigation of the chief constituents of the animal body; and the circumstance, that the researches thus entered on are not yet quite completed, is the reason why the second and concluding portion of this edition cannot be published for some weeks.

GIESSEN,
26*th September*, 1846.

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THE CHEMICAL PROCESS

OF

RESPIRATION AND NUTRITION.

I. In the animal ovum, as well as in the seed of a plant, we recognize a certain remarkable force, the source of growth, or increase in the mass, and of reproduction, or of supply of the matter consumed; a force in a state of rest. By the action of external influences, by impregnation, by the presence of air and moisture, the condition of static equilibrium of this force is disturbed; entering into a state of motion or activity, it exhibits itself in the production of a series of forms, which, although occasionally bounded by right lines, are yet widely distinct from geometrical forms, such as we observe in crystallized minerals. This force is called the *vital force*, *vis vitæ*, or *vitality*. Vital force.

The increase of mass in a plant is determined by the occurrence of a decomposition which takes place in certain parts of the plant under the influence of light and heat.

In the vital process, as it goes on in vegetables, it is exclusively inorganic matter which undergoes this decomposition; and if, with the most distinguished mineralogists, we consider atmospherical air and certain other gases as minerals, it may be said that the vital process in vegetables accomplishes the transformation of mineral substances into an organism endued with life; that the mineral becomes part of an organ possessing vital force. Life in vegetables.

The increase of mass in a living plant implies that certain component parts of its nourishment become component parts of the plant; and a comparison of the chemical composition of the plant with that of its nourishment makes known to us, with positive

certainty, which of the component parts of the latter have been assimilated, and which have been rejected.

The observations of vegetable physiologists and the researches of chemists have mutually contributed to establish the fact, that the growth and development of vegetables depend on the elimination of oxygen, which is separated from the other component parts of their nourishment.

Life in animals.

In contradistinction to vegetable life, the life of animals exhibits itself in the continual absorption of the oxygen of the air, and its combination with certain component parts of the animal body.

While no part of an organized being can serve as food to vegetables, until, by the processes of putrefaction and decay, it has assumed the form of inorganic matter, the animal organism requires, for its support and development, highly organized atoms. The food of all animals, in all circumstances, consists of parts of organisms.

Vegetative life.

Assimilation, or the process of formation and growth—in other words, the passage of matter from a state of motion to that of rest—goes on in the same way in animals and vegetables. In both, the same cause determines the increase of mass. This constitutes the true vegetative life, which is carried on without consciousness, and is the same as that of the plant.

The activity of vegetative life manifests itself, in vegetables, with the aid of external influences; in animals, by means of influences produced within their organism. Digestion, absorption, the circulation of the blood, nutrition, and secretion are essentially dependent on the same power which gives to the germ, to the leaf, and to the radical fibres of the vegetable, their wonderful properties.

Is independent of the organs of motion.

Animals are, in general, distinguished from vegetables by the faculty of locomotion, and by the possession of consciousness.

The existence and activity of these distinguishing faculties depend on certain instruments which are never found in vegetables. Comparative anatomy shows, that the phenomena of motion and sensation depend on certain kinds of apparatus, muscles, nerves, and organs of sense, of which no trace can be found in plants.

The phenomena of motion in vegetables, the circulation of the sap, for example, observed in many plants, and the closing of flowers and leaves, depend chiefly on physical and mechanical causes acting externally. Heat and light are the remote causes of motion in vegetables; but in animals we recognize in the muscles and nerves a source of power, a cause of motion, which we do not find in plants.

The effects produced by the organs of motion, of sensation, and of consciousness, exert, however, on the processes of formation and nutrition only a determinative influence; but essentially these processes are carried on in the same way in the animal and in the plant.

Independent also of the organs of sense and of the nerves.

The processes of formation and nutrition go on, in those animals and parts of animals which have no nerves, in the same way as where nerves are present. Experimental physiology and pathology inform us that the true vegetative life is in no way dependent on the presence of the nervous apparatus; and that the process of nutrition often proceeds in those parts of the body where the nerves of sensation and voluntary motion are divided or paralyzed, almost exactly in the same way as in other parts where these nerves are in a normal condition.

The higher phenomena of mental existence cannot, in the present state of science, be referred to their proximate, and still less to their ultimate causes. We only know of them, that they exist; if we ascribe them to an immaterial agency, and that, in so far as its manifestations are connected with matter, a power, then must this power be entirely distinct from the vital force, with which it has nothing in common.

It cannot be denied that this peculiar force exercises a certain influence on the activity of vegetative life, just as other immaterial agents, such as Light, Heat, Electricity, and Magnetism do; but this influence is not of a determinative kind, and manifests itself only as an acceleration, a retarding, or a disturbance of the process of vegetative life. In a manner exactly analogous, the vegetative life re-acts on the conscious mental existence.

There are thus two forces which are found in activity together; but consciousness and intellect may be absent in animals as they

are in living vegetables, without their vitality being otherwise affected than by a want of a peculiar source of increased energy or of disturbance. Except in regard to this, all the vital chemical processes go on precisely in the same way in man and in the lower animals.

The soul is no object for physical investigation.

The efforts of philosophers, constantly renewed, to penetrate the relations of the soul to animal life, have all along retarded the progress of physiology. In this attempt men left the province of philosophical research for that of fancy; physiologists, carried away by imagination, were far from being acquainted with the laws of purely animal life. They had only a one-sided notion of the process of development and nutrition, or of the true cause of death.

For the purpose of investigating the laws of vital motion in the animal body, only one condition, namely, the knowledge of the apparatus which serves for its production, was ascertained; but the substance of the organs, the changes which food undergoes in the living body, its transformation into portions of organs, and its re-conversion into lifeless compounds, the share which the atmosphere takes in the processes of vitality; all these foundations for future conclusions were still wanting.

What has the soul, what have consciousness and intellect to do with the development of the human fœtus, or the fœtus in a fowl's egg? not more, surely, than with the development of the seeds of a plant. Let us first endeavor to refer to their ultimate causes those phenomena of life which are not psychological; and let us beware of drawing conclusions before we have a groundwork. We know exactly the mechanism of the eye; but neither anatomy nor chemistry will ever explain how the rays of light act on consciousness, so as to produce vision. Natural science has fixed limits which cannot be passed; and it must always be borne in mind that, with all our discoveries, we shall never know what light, electricity, and magnetism are in their essence, because, even of those things which are material, the human intellect has only conceptions. We can ascertain, however, the laws which regulate their motion and rest, because these are manifested in phenomena. In like manner, the laws of vitality, and of all that disturbs, promotes, or alters it, may certainly be discovered,

although we shall never learn what life is. Thus the discovery of the laws of gravitation and of the planetary motions led to an entirely new conception of the cause of these phenomena. This conception could not have been formed in all its clearness without a knowledge of the phenomena out of which it was evolved; for, considered by itself, gravity, like light to one born blind, is a mere word, devoid of meaning.

The modern science of physiology has left the track of Aristotle. To the eternal advantage of science, and to the benefit of mankind, it no longer invents a *horror vacui*, a *quinta essentia*, in order to furnish credulous hearers with solutions and explanations of phenomena, whose true connection with others, whose ultimate cause is still unknown.

Conditions of the manifestation of the vital force.

If we assume that all the phenomena exhibited by the organism of plants and animals are to be ascribed to a peculiar cause, different in its manifestations from all other causes which produce motion or change of condition; if, therefore, we regard the vital force as an independent force, then, in the phenomena of organic life, as in all other phenomena ascribed to the action of forces, we have the *statics*, that is, the state of equilibrium determined by a resistance, and the *dynamics*, of the vital force.

All the parts of the animal body are produced from a peculiar fluid, circulating in its organism by virtue of an influence residing in every cell, in every organ, or part of an organ. Physiology teaches that all parts of the body were originally blood; or that at least they were brought to the growing organs by means of this fluid.

The change of matter.

The most ordinary experience further shows, that at each moment of life, in the animal organism, a continued change of matter, more or less accelerated, is going on; that a part of the structure is transformed into unorganized matter, loses its condition of life, and must be again renewed. Physiology has sufficiently decisive grounds for the opinion, that every motion, every manifestation of force is the result of a transformation of the structure or of its substance; that every conception, every mental affection, is followed by changes in the chemical nature of the secreted fluids; that every thought, every sensation,

is accompanied by a change in the composition of the substance of the brain.

In order to keep up the phenomena of life in animals, certain matters are required, parts of organism, which we call *food or nourishment.* In consequence of a series of alterations, they serve either for the increase of the mass (*nutrition*), or for the supply of the matter consumed (*reproduction*).

II.

Reproduction and nutrition

If the first condition of animal life be the assimilation of what is commonly called nourishment, the second is a continual absorption of oxygen from the atmosphere.

Viewed as an object of scientific research, animal life exhibits itself in a series of phenomena, the connection and recurrence of which are determined by the changes which the food and the oxygen absorbed from the atmosphere undergo in the organism under the influence of the vital force.

All vital activity arises from the mutual action of the oxygen of the atmosphere and the elements of the food.

In the processes of nutrition and reproduction, we perceive the passage of matter from the state of motion to that of rest (static equilibrium).

The cause of the state of rest is a resistance, determined by a force of attraction (combination), which acts between the smallest particles of matter, and is manifested only when these are in actual contact, or at infinitely small distances.

Affinity, a co-operating cause.

To this peculiar kind of attraction we may of course apply different names; but the chemist calls it *affinity.*

The cause of the state of motion is to be found in a series of changes which the food undergoes in the organism, and these are the results of processes of decomposition, to which either the food itself, or the structures formed from it, or parts of organs, are subjected.

In plants, there is no waste of matter from internal causes.

The distinguishing character of vegetable life is a continued passage of matter from the state of motion to that of static equilibrium. While a plant lives, we

cannot perceive any cessation in its growth; no part of an organ in the plant diminishes in size. If decomposition occur, it is the result of assimilation. In the plant no part of its structure, from any influence residing in its organism, loses its state of vitality, and is converted into unorganized, amorphous compounds; in a word, no waste occurs in vegetables.

Influence of chemical actions on the animal body.

Waste in the animal body, is a change in the state or in the composition of some of its parts, and consequently is the result of chemical actions. The influence of poisons and of remedial agents on the living animal body evidently shows that the chemical decompositions and combinations in the body, which manifest themselves in the phenomena of vitality, may be increased in intensity by chemical forces of *analogous* character, and retarded or put an end to by those of *opposite* character; and that we are enabled to exercise an influence on every part of an organ by means of substances possessing a well-defined chemical action.

As, in the closed galvanic circuit, in consequence of certain changes which an inorganic body, a metal, undergoes when placed in contact with an acid, a certain something becomes cognizable by our senses, which we call a current of electricity; so, in the animal body, *in consequence* of transformations and changes undergone by matter previously constituting a part of the organism, certain phenomena of motion and activity are perceived, and these we call life, or vitality.

The electrical current manifests itself in certain phenomena of attraction and repulsion, which it excites in other bodies naturally motionless, and by the phenomena of the formation and decomposition of chemical compounds, which occur everywhere, when the resistance is not sufficient to arrest the current.

It is from this point of view, and from no other, that *Chemistry* ought to contemplate the phenomena of life. Wonders surround us on every side. The formation of a crystal, of an octahedron, is not less incomprehensible than the production of a leaf or of a muscular fibre; and the production of vermilion from mercury and sulphur is as much an enigma as the formation of an eye from the substance of the blood.

The first conditions of animal life are nutritious matters and oxygen, introduced into the system.

Introduction of oxygen into the system.

At every moment of his life man is taking oxygen into his system, by means of the organs of respiration; no pause is observable while life continues.

The observations of physiologists have shown that the body of an adult man, supplied with sufficient food, has neither increased nor diminished in weight at the end of twenty-four hours; yet the quantity of oxygen taking into the system during this period is very considerable.

According to the experiments of Lavoisier, an adult man takes into his system, from the atmosphere, in one year, 746 lbs.; according to Menzies, 837 lbs. of oxygen; yet we find his weight, at the beginning and end of the year, either quite the same, or differing, one way or the other, by at most a few pounds. (1)*

This oxygen does not remain in the body.

What, it may be asked, has become of the enormous weight of oxygen thus introduced, in the course of a year, into the human system?

This question may be answered satisfactorily: no part of this oxygen remains in the system; but it is given out again in the form of a compound of carbon or of hydrogen.

It is given out as water and carbonic acid.

The carbon and hydrogen of certain parts of the body have entered into combination with the oxygen introduced through the lungs and through the skin, and have been given out in the forms of carbonic acid gas and the vapor of water.

At every moment, with every expiration, certain quantities of its elements separate from the animal organism, after having entered into combination, within the body, with the oxygen of the atmosphere.

If we assume, with Lavoisier, and Séguin, in order to obtain a foundation for our calculation, that an adult man receives into his system daily 32½ oz. (46,037 cubic inches=15,661 grains, French weight,) of oxygen, and that the weight of the whole mass of his blood, of which 80 per cent. is water, is 24 lbs.; it then appears from the known composition of the blood, that, in order to con-

* The Numbers refer to the Appendix.

vert the whole of its carbon and hydrogen into carbonic acid and water, 64,103 grains of oxygen are required, and that this quantity will be taken into the system of an adult in four days five hours. (2)

Whether this oxygen enters into combination with the elements of the blood, or with other parts of the body containing carbon and hydrogen, in either case the conclusion is inevitable, that the body of a man, who daily takes into the system $32\frac{1}{2}$ oz. of oxygen, must receive, in the space of four days five hours, in the shape of nourishment, as much carbon and hydrogen as would suffice to supply 24 pounds of blood with these elements; it being presupposed that the weight of the body remains unchanged, and that it retains its normal conditions as to health.

The food.

This supply is furnished in the food.

From the accurate determination of the quantity of carbon daily taken into the system in the food, as well as of that proportion of it which passes out of the body in the fæces and urine, unburned, that is, not in the form of a gaseous compound of oxygen, it appears that an adult, taking moderate exercise, consumes 13·9 oz. of carbon daily. (3)

Amount of oxygen given out as carbonic acid.

These $13\frac{9}{10}$ oz. of carbon escape through the skin and lungs as carbonic acid gas.

For conversion into carbonic acid gas, $13\frac{9}{10}$ oz. of carbon require 37 oz. of oxygen.

According to the analyses of Boussingault, a pig, five months old, weighing $64\frac{4}{10}$ lbs., gives out daily $11\frac{1}{4}$ oz.; a pig, eight months old, weighing 120 lbs., gives out daily $21\frac{1}{6}$ oz. of carbon in the form of carbonic acid (that is, for equal weights, very nearly equal quantities): a horse consumes in the same time $79\frac{1}{10}$ oz., and a milch cow $70\frac{3}{4}$ oz. of carbon. (4)

The restoration of the equilibrium.

Since no part of the oxygen taken into the system is again given off in any other form but that of a compound of carbon and hydrogen; since further, in the normal state of health, the carbon and hydrogen given off are replaced by carbon and hydrogen supplied in the food, it is clear that the amount of nourishment required by the animal body for its support, provided its weight is to remain unaltered, must be in a direct ratio to the quantity of oxygen taken into the system.

Is arranged according to the consumption of oxygen.

Two animals, which in equal times take up by means of the lungs and skin unequal quantities of oxygen, consume quantities of the same nourishment which are unequal in the same ratio.

This depends, in an individual, on the number of respirations.

The consumption of oxygen in equal times may be expressed by the number of respirations; it is clear that, in the same individual, the quantity of nourishment required must vary with the force and number of the respirations.*

A child, in whom the organs of respiration are naturally very active, requires food oftener, and in proportion, more abundantly, than an adult, and bears hunger less easily. A bird, deprived of food, dies on the third day, while a serpent, which, when confined in a bell jar of air, hardly consumes in an hour so much oxygen that the carbonic acid formed is appreciable, can live without food three months and longer.

Respirations depend on exercise;

The number of respirations is smaller in a state of rest than during exercise or work. The quantity of food necessary in both conditions must vary in the same ratio.

An excess of food is incompatible with deficiency in respired oxygen, that is, with deficient exercise; just as violent exercise, which implies an increased supply of food, is incompatible with weak digestive organs. In either case the health suffers.

But the quantity of oxygen inspired is also affected by the temperature and density of the atmosphere.

on the temperature and density of the air.

The capacity of the chest in an animal is a constant quantity. At every respiration a quantity of air enters, the volume of which may be considered as uniform; but its weight, and consequently that of the oxygen it contains, is not constant. Air is expanded by heat, and contracted by cold, and therefore equal volumes of hot and cold air contain unequal weights of oxygen. In summer, moreover, atmospherical air contains aqueous vapor, while in winter it is dry; the space occupied by vapor in the warm air is filled up by air itself in win-

* See the classical work of Vierordt; "The Physiology of Respiration." Carlsruhe.

ter; that is, it contains, for the same volume, more oxygen in winter than in summer.

The consumption of oxygen is greater in winter than in summer.

In summer and in winter, at the pole and at the equator, we respire an equal volume of air; the cold air is warmed during respiration, and acquires the temperature of the body. To introduce into the lungs a given volume of oxygen, less expenditure of force is necessary in winter than in summer; and for the same expenditure of force, more oxygen is inspired in winter.

It is greater at the level of the sea than on mountains.

It is obvious, that in an equal number of respirations we consume more oxygen at the level of the sea than on a mountain. The quantity both of oxygen inspired and of carbonic acid expired, must therefore vary with the height of the barometer.

The oxygen taken into the system is given out again in the same forms, whether in summer or in winter; hence we expire more carbon in cold weather, and when the barometer is high, than we do in warm weather; and we must consume more or less carbon in our food in the same proportion; in Sweden more than in Sicily; and in our more temperate climate a full eighth more in winter than in summer.

Even when we consume equal weights of food in cold and warm countries, infinite wisdom has so arranged, that the articles of food in different climates are most unequal in the proportion of carbon they contain. The fruits on which the natives of the south prefer to feed, do not in the fresh state contain more than 12 per cent. of carbon, while the blubber and train oil used by the inhabitants of the arctic regions contain from 66 to 80 per cent. of carbon.

It is no difficult matter, in warm climates, to study moderation in eating, and men can bear hunger for a long time under the equator; but cold and hunger united very soon exhaust the body.

The source of animal heat.

The mutual action between the elements of the food and the oxygen conveyed by the circulation of the blood to every part of the body is THE SOURCE OF ANIMAL HEAT.

III.

There is development of heat

All living creatures, whose existence depends on the absorption of oxygen, possess within themselves a source of heat independent of surrounding objects. This truth applies to all animals, and extends, besides, to the germination of seeds, to the flowering of plants, and to the maturation of fruits.

It is only in those parts of the body to which arterial blood, and with it the oxygen absorbed in respiration, is conveyed, that heat is produced. Hair, wool, or feathers do not possess an elevated temperature.

wherever oxygen enters into combination.

This high temperature of the animal body, or, as it may be called, disengagement of heat, is uniformly and under all circumstances the result of the combination of a combustible substance with oxygen.

It is independent of the form of the products.

In whatever form the combustible elements may combine with oxygen, the act of combination cannot take place without the disengagement of heat. It is a matter of indifference whether the combination take place rapidly or slowly, at a high or at a low temperature; the amount of heat liberated is a constant quantity.

The amount of heat does not depend on the time,

If we suppose the carbon of the food to be converted into carbonic acid within the body, it must give out exactly as much heat as if it had been directly burnt in the air or in oxygen gas; the only difference is, that the amount of heat produced is diffused over unequal times. In pure oxygen, the combustion is more rapid, and the heat more intense; in air it is slower, the temperature is not so high, but it continues longer.

but is directly proportional to the oxygen consumed.

It is obvious that the amount of heat liberated must increase or diminish with the quantity of oxygen introduced in equal times by respiration. Those animals which respire frequently, and consequently consume much oxygen, can give out more heat to surrounding bodies than others, which, with a body of equal size to be heated, take into the system less oxygen. The temperature of a child (102°) is higher

than that of an adult (99·5°). That of birds (104° to 105·4°) is higher than that of quadrupeds (98·5° to 100·4°) or than that of fishes or amphibia, whose proper temperature is from 2·7° to 3·6° higher than that of the medium in which they live. (5.) All animals, strictly speaking, are warm-blooded; but in those only which possess lungs, and the whole mass of whose blood is sent through the lungs, is the temperature of the body quite independent of the surrounding medium.

Limits of the development of heat.

The amount of oxygen capable of being taken up in the animal body in a given time is limited by the quantity of oxygen which can come into contact with the blood, and of blood which can come into contact with the oxygen. Both may be expressed by the number of respirations and of pulsations: to these, taken together, the number of degrees of heat set free is proportional, and it is consequently easy to explain how it happens, that the heat which an individual can give off to surrounding bodies in a certain time does not exceed a certain limit. In what manner evaporation, cooling by radiation, and the formation of gaseous matter going on in the body, that is, the conversion into gaseous compounds of the elements of the food, co-operate to produce in each individual the peculiar temperature of the body, is altogether unknown.

The temperature of the human body is everywhere the same.

The most trustworthy observations prove that in all climates, in the temperate zones as well as at the equator or the poles, the temperature of the body in man, and in what are commonly called warm-blooded animals, is invariably the same; yet how different are the circumstances under which they live!

The animal body is a heated mass, which bears the same relation to surrounding objects as any other heated mass. It receives heat when the surrounding objects are hotter, it loses heat when they are colder than itself.

We know that the rapidity of cooling increases with the difference between the temperature of the heated body and that of the surrounding medium; that is, the colder the surrounding medium, the shorter the time required for the cooling of the heated body.

How unequal, then, must be the loss of heat in a man at Palermo, where the external temperature is nearly equal to that

of the body, and in the polar regions, where the external temperature is from 70° to 90° lower!

It is, to a certain degree, independent of the external temperature.

Yet, notwithstanding this extremely unequal loss of heat, experience has shown that the blood of the inhabitant of the arctic circle has a temperature as high as that of the native of the south, who lives in so different a medium.

The heat lost by cooling is quickly restored

This fact, when its true significance is perceived, proves that the heat given off to the surrounding medium is restored within the body with great rapidity. This compensation takes place more rapidly in winter than in summer, at the pole than at the equator.

External conditions of this replacement of heat.

Now, in different climates the quantity of oxygen introduced into the system by respiration, as has been already shown, varies according to the temperature of the external air; the quantity of inspired oxygen increases with the loss of heat by external cooling, and the quantity of carbon or hydrogen necessary to combine with this oxygen must be increased in the same ratio.

By what means this replacement is effected.

It is evident that the supply of heat lost by cooling is effected by the mutual action of the elements of the food and the inspired oxygen, which combine together. To make use of a familiar, but not on that account a less just illustration, the animal body acts, in this respect, as a furnace, which we supply with fuel. It signifies nothing what intermediate forms food may assume, what changes it may undergo in the body, the last change is uniformly the conversion of its carbon into carbonic acid, and of its hydrogen into water; the unassimilated nitrogen of the food, along with the unburned or unoxidized carbon, is expelled in the urine or in the solid excrements. In order to keep up in the furnace a constant temperature, we must vary the supply of fuel according to the external temperature, that is, according to the supply of oxygen.

In the animal body the food is the fuel; with a proper supply of oxygen we obtain the heat given out during its oxidation or combustion. In winter, when we take exercise in a cold atmosphere, and when consequently the amount of inspired oxygen increases, the necessity for food containing carbon and hydrogen

increases in the same ratio ; and by gratifying the appetite thus excited, we obtain the most efficient protection against the most piercing cold. A starving man is soon frozen to death ; and every one knows that the animals of prey in the arctic regions far exceed in voracity those of the torrid zone.

In cold and temperate climates, the air, which incessantly strives to consume the body, urges man to laborious efforts in order to furnish the means of resistance to its action, while in hot climates, the necessity of labor to provide food is far less urgent.

Influence of clothing on the amount of food.

Our clothing is, in reference to the temperature of the body, merely an equivalent for a certain amount of food. The more warmly we are clothed, the less urgent, up to a certain point, becomes the appetite for food, because the loss of heat by cooling, and consequently the amount of heat to be supplied by the food, is diminished.

If we were to go naked, like certain savage tribes, or if in hunting or fishing we were exposed to the same degree of cold as the Samoyedes, we should be able with ease to consume 10 lbs. of fish or flesh, and perhaps a dozen of tallow candles into the bargain, daily, as warmly-clad travellers have related with astonishment of these people. We should then also be able to take the same quantity of brandy or train oil without bad effects, because the carbon and hydrogen of these substances would only suffice to keep up the equilibrium between the external temperature and that of our bodies.

The amount of food to be taken.

According to the preceding expositions, the quantity of food is regulated by the consumption of oxygen, which bears a fixed proportion to the number of respirations, to the temperature of the air, and to the amount of heat given off to the surrounding medium.

is determined by cooling and exercise,

No isolated fact, apparently opposed to this statement, can affect the truth of this natural law.

The cooling of the body, by whatever cause it may be produced, increases the amount of food necessary. The mere exposure to the open air, in a carriage or on the deck of a ship, by increasing radiation and vaporization, increases the loss of heat, and compels us to eat more than usual. The same is true of those who are accustomed to drink large quan-

by the drinking of cold water,

tities of cold water, which is given off at the temperature of the body, 98.5°. It increases the appetite, and persons of weak constitution find it necessary, by continued exercise, to supply to the system the oxygen required to restore the heat abstracted by the cold water. Loud and long-continued speaking and singing, the crying of infants, moist air, all exert a decided and appreciable influence on the amount of food which is taken.

by speaking and singing.

The unequal loss of heat in summer and winter, in a warm or a cold climate, is only one of the conditions which render necessary unequal amounts of food. The supply of the waste of matter, and the amount of oxygen taken into the body in a given time, determine, in all seasons, and in all climates, the quantity of food necessary to restore the equilibrium.

Exercise is the last and principal condition affecting the consumption of oxygen and of food.

While the working man is compelled, the consumption of force and of oxygen being equal, to prevent, in winter, the loss of heat by means of warm clothing, (bad conductors of heat,) in summer he finds himself, when at work, bathed in perspiration. If the consumption of food and of oxygen is the same at the two periods, then the heat disengaged is also equal; in the one case the loss of heat appears as a simple cooling by radiation and evaporation; in the other it is also seen in the larger amount of water, which, without a rise in the temperature of the body, is converted into the gaseous form.

IV.

Importance of hydrogen.

In the foregoing pages it has been assumed that it is especially carbon and hydrogen which, by combining with oxygen, serve to produce animal heat. In fact, observaing proves that the hydrogen of the food plays a not less important part than the carbon.

The whole process of respiration appears most clearly developed when we consider the state of a man, or other animal, totally deprived of food. The respiratory motions remain unaltered; oxygen is absorbed from the atmosphere and carbonic acid and water

are exhaled, just as before. We know with certainty whence this carbon and hydrogen are derived; for with the duration of the hunger or starvation we see the carbon and hydrogen of the body diminish.

Effects of starvation.

The first effect of starvation is the disappearance of fat, and this fat cannot be traced either in the urine or in the scanty fæces. Its carbon and hydrogen have been given off through the skin and lungs in the form of oxodized products; it is obvious that they have served to support respiration.

Each day oxygen enters the system, and in its exit takes along with it a part of the body of the starving animal. Currie mentions the case of an individual who was unable to swallow, and whose body lost 100 lbs. in weight during a month; and, according to Martell, (Trans. Linn. Soc., vol. xi. p. 411,) a fat pig, overwhelmed in a slip of earth, lived 160 days without food, and was found to have diminished in weight, in that time, more than 120 lbs. The whole history of hybernating animals, and the well-established facts of the periodical accumulation, in various animals, of fat, which, at other periods, entirely disappears, and the elimination of the alcohol consumed in fermented liquors in the forms of carbonic acid and water, prove that the oxygen, in the respiratory process, consumes, without exception, all such substances as are capable of entering into combination with it. It combines, provided no obstacle to its action exists, with whatever is presented to it.

Facts.

The presence of fat in the food of man and of animals, and the fact that alcohol is given out in the shape of gaseous compounds, these phenomena point out that the elements of fat and of alcohol capable of combining with oxygen, and consequently their hydrogen, take a share in the respiratory process.

Effect of respiration on the air.

The air, in which an animal breathes, in whose body the inspired oxygen is converted into carbonic acid alone, cannot experience any change in its volume, because the *oxygen inspired* and the *carbonic acid expired* contain the same volume of oxygen gas. As much oxygen, by volume, as the blood absorbs from the atmosphere, is again returned to it in the shape of carbonic acid.

The air, in which an animal breathes, in whose body the ab-

sorbed oxygen combines with hydrogen to form water, must, on the other hand, suffer a diminution in volume. The portion of oxygen which has been absorbed by the blood and has been converted into water, can only be measured by a diminution in the volume of the air, inasmuch as that oxygen is condensed into liquid water.

The loss of volume proves that water is formed.

The existing observations perfectly agree in this, that the air, in which an animal breathes, always and under all circumstances diminishes in volume; and the relation of this condensation or loss of volume to the food most decidedly shows that it bears a direct proportion to the quantity of fat, or to speak more generally, of hydrogenized compounds, in the food.

Facts observed.

The herbivora return to the atmosphere, in the form of carbonic acid, only 9 out of 10 volumes of oxygen introduced into their bodies in the blood; and the carnivora only return, in the same form, from 5 to 6 volumes of the absorbed oxygen. (Dulong. Despretz.) The use of alcoholic liquors causes a considerable diminution in the amount of carbonic acid given out.

Besides carbon and a small proportion of sulphur, the animal body contains, as a combustible element with which oxygen can combine, only hydrogen; and it must be viewed as an established fact, that in the body of an herbivorous animal which out of 10 volumes of oxygen only exhales 9 in the form of carbonic acid, the tenth volume, and in the body of a carnivorous animal, on the other hand, four or five times as much, of oxygen is consumed in the formation of water.

The more exact analysis of the process of respiration will show, that the production of carbonic acid is dependent on a formation of water, and that these two operations cannot be imagined as separate from each other. Hence it naturally follows, that the consumption of carbon in the animal body, or the determination of the quantity of carbonic acid exhaled in a given time, can furnish no measure of the entire process of respiration; and finally that all experiments, in which the relation of the food to the entire consumption of oxygen is not taken into consideration, are faulty and possess only a relative value.

In the progress of starvation, however, it is not only the fat

which disappears, but also, by degrees, all such of the solids as are capable of being dissolved. In the wasted bodies of those who have suffered starvation, the muscles are shrunk and unnaturally soft, and have lost their contractility; all those parts of the body which were capable of entering into the state of motion have served to protect the remainder of the frame from the all-destroying influence of the atmosphere. Towards the end, the particles of the brain begin to undergo the process of oxidation, and delirium, mania, and death close the scene; that is to say, all resistance to the oxidizing power of the atmospheric oxygen ceases, and the chemical process of eremacausis, or decay, commences, in which every part of the body enters into combination with oxygen.

Time in which starvation causes death.

The time which is required to cause death by starvation depends on the amount of fat in the body, on the degree of exercise, as in labor or exertion of any kind, on the temperature of the air, and finally, on the presence or absence of water. Through the skin and lungs there escapes a certain quantity of water, and as the presence of water is essential to the continuance of the vital motions, its dissipation hastens death. Cases have occurred, in which a full supply of water being accessible to the sufferer, death has not occurred till after the lapse of twenty days. In one case, life was sustained in this way for the period of sixty days.

The respiratory process is the cause of death.

In most chronic diseases death is produced by the same cause, namely, the chemical action of the atmosphere. When those substances are wanting, whose function in the organism is to support the process of respiration; when the diseased organs are incapable of performing their proper function of producing these substances; when they have lost the power of transforming the food into that shape in which it may, by entering into combination with the oxygen of the air, protect the system from its influence, then, the substance of the organs themselves, the fat of the body, the substance of the muscles, the nerves and the brain, are unavoidably consumed.*

* For an account of what really takes place in this process, I refer to the considerations on the means by which the change of matter is effected in the body of the carnivora, which will be found further on.

The true external cause of death in these cases is the respiratory process, that is, the action of the atmosphere.

A deficiency of food, and a want of power to convert the food into a part of the organism, are both, equally, a want of resistance; and this is the negative cause of the cessation of the vital process. The flame is extinguished, because the oil is consumed; and it is the oxygen of the air which has consumed it.

Starvation as a remedy.

In many diseases substances are produced which are incapable of assimilation. By the mere deprivation of food, these substances are removed from the body without leaving a trace behind; their elements have entered into combination with the oxygen of the air.

From the first moment that the function of the lungs or of the skin is interrupted or disturbed, compounds, rich in carbon, appear in the urine, which acquires a brown color. Over the whole surface of the body oxygen is absorbed, and combines with all the substances which offer no resistance to it. In those parts of the body where the access of oxygen is impeded; for example, in the arm-pits, or in the soles of the feet, peculiar compounds are given out, recognizable by their appearance, or by their odor.

Respiration is the falling weight, the bent spring, which keeps the clock in motion; the respirations and pulsations are the strokes of the pendulum which regulate it. In our ordinary time-pieces, we know with mathematical accuracy the effect produced on their rate of going, by changes in the length of the pendulum, or in the external temperature. Few, however, have a clear conception of the influence of air and temperature on the health of the human body: and yet the research into the conditions necessary to keep it in the normal state, is not more difficult than in the case of a clock.

The view above developed of the action of oxygen in the animal organism, cannot be endangered in its truth by the usual relation of oxygen to fat or to animal matters out of the body.

Conditions of the action of oxygen.

It is only in a very few cases that the oxygen of the atmosphere combines directly and immediately with those substances for which it has an attraction. In order to bring about their combination with oxygen, other conditions are required, which either, like heat, for example, assist in

exalting the mutual affinity, or which are necessary to overcome the obstacles which oppose the exertion of the chemical force of oxygen.

It acts in the liquid or solid form,

There are not many bodies whose attraction for oxygen is so great as that of sulphurous acid; and yet it is impossible to cause these bodies, in their ordinary condition, to combine so as to form sulphuric acid. But if finely divided platinum be introduced into the mixture of the two gases, in which case the oxygen, by virtue of an attraction residing on the surface of the metal, loses its gaseous form, they immediately unite, forming sulphuric acid. The same thing happens when sulphurous acid is added to water which contains dissolved air, that is, oxygen in the liquid form, or when the aqueous solution of sulphurous acid (that is, in the liquid state) is left in contact with the air. In like manner the oxygen of the air exerts no oxidizing agency on sulphuret of lead; but if this compound is brought in contact with peroxide of hydrogen, which, as we know, contains half its oxygen so loosely combined as to be set free by mere agitation with a foreign body, the black sulphuret is at once converted into white sulphate of lead.

not in that of gas.

The cause of the different action of oxygen in the body and out of the body is thus rendered clear. In the blood, the oxygen is contained, not in the gaseous, but in the liquid or solid form, and indeed in the most loose form of combination, which allows it to exert in full force its oxidizing power, just as is known by numberless experiments to be the case with liquid and solid oxygen in similar compounds.

V.

The form of the oxygen is not the only condition.

The circumstance that the oxygen contained in the blood is in the solid or liquid state, is not the only condition on which depends, in the organism, the conversion of combustible elements into oxidized compounds. Another condition is the enormously increased surface over which, in consequence of the extremely minute division of the blood in the capillary circulation, those substances which possess an attrac-

tion for oxygen are exposed to the action of that element in the system.

Influence of surface.

The influence of surface on chemical actions is universally known. The clean polished surface of a piece of iron, when moistened with water, absorbs oxygen from the atmosphere, and combines with it to produce an oxide; after some days or weeks it is found covered with rust, that is, with oxide. But if we expose to the air metallic iron in the spongy, porous, and highly divided state in which it occurs when the oxide is reduced by hydrogen at the lowest possible temperature, it takes fire in a few seconds spontaneously, glows, and is converted into oxide. (Magnus.)

The same property resides in a no less eminent degree in organic substances, especially in fats and oils. Wool, hair, or cloth, impregnated with these compounds, absorb oxygen from the atmosphere with great avidity, heat is disengaged, and when the mass is considerable, the temperature may then rise to the point at which vivid combustion takes place. This, indeed, is the theory of many spontaneous combustions.

Contact with a body which is actually combining with oxygen.

A not less important influence is exerted on the process of the combination of oxygen of many substances not readily combustible by the contact of other substances, which are already in the act of combining with oxygen. When weak brandy is allowed to trickle over shavings in a closed vessel, through which a feeble current of air, at from 93° to 97° F. circulates, the alcohol in the brandy remains unchanged; in spite of the greatly increased surface, no oxidation, no formation of acetic acid takes place. But if to the brandy there be added one-hundred thousandth part of vinegar, beer, or wine, in a state of acetification, that is of oxidation, the alcohol disappears with great rapidity, and is converted, by the absorption of oxygen, into an equivalent quantity of acetic acid. In the vessel, the surface of the shavings themselves very soon passes into the state of oxidation, and from this period forth the brandy is acetified without the addition of a ferment; the wood, being in the state of decay, eremacausis, or slow combustion, plays the part of the ferment.

These vinegar-producing vats give an idea, if only a rough one,

of the process of oxidation going on in the animal body. As in the body, so also in these vessels, a temperature higher than that of the surrounding media is kept up, without the aid of external heat.

Examples of the communication of the state of oxidation.

The most beautiful example of the transference or communication of the state of chemical activity by contact, is given by decaying wood and hydrogen gas. Oxygen and hydrogen are among those substances which have the strongest mutual affinity; but in the ordinary gaseous form they do not combine. A red-hot wire, an electrical spark, or a bit of clean platinum foil, will suffice to cause the two gases to unite and form water, as is well known. But the most remarkable fact is this, that the same effect is produced, exactly in the same way, by moist decaying wood, silk, cotton, garden mould, and in general by organic substances which are in the act of absorbing oxygen.

If these substances are placed in a vessel filled with air, or with oxygen, over mercury, the whole oxygen gradually disappears, and in its place is found an equal volume of carbonic acid gas, so that the mercury neither rises nor falls in the tube. But if to the air or oxygen a known volume of hydrogen be added, the rising of the mercury soon shows a diminution in the volume of the confined gases, which goes on until all the hydrogen present has disappeared.

From the diminution of volume which occurs, it appears that not only hydrogen, under these circumstances, disappears, but also, with this hydrogen, a certain quantity of oxygen, which produces no carbonic acid. Both gases disappear in the proportion in which they unite to form water; so that there cannot be the slightest doubt that the hydrogen has united with oxygen to form water.

The action of the decaying body on the mixture of oxygen and hydrogen has no analogy with that of electricity or of heat. When, by means of the electric spark, or of a red-hot wire, the combination of even the smallest portion of the mixture is effected, the combustion spreads through the whole mass, suddenly and with explosion; but with the aid of decaying wood, the combination goes on quite gradually; the cause of the difference can be no

other than this, namely, that every particle of the mixture, in order to be converted into water, must come into contact with the decaying body. The formation of vinegar from brandy, by contact with the decaying wood, depends on the same cause; and it appears that even the peculiar phenomena of fermentation and putrefaction depend on similar conditions.

Distinction between these and chemical actions not tied down to time.

These processes of decomposition and transformation take place in a multitude of compound substances when in contact with others, the atoms of which are in a state of transformation, that is of motion; and they are distinguished from all ordinary chemical processes by this, that they do not by mere contact commence, and then go on to completion, in a space of time too short to be measured: but that they have a determinate course, tied down to time, and this course is exactly limited by the completion of the separation or transformation of the exciting body, as, for example, of the yeast or of the decaying wood.

This cause

These phenomena show that the one body, hydrogen, for example, behaves exactly as if it were a constituent of the other body, for example, of the decaying wood, the particles of which are in a state of activity. Exactly in the same way do sugar and analogous bodies behave, in contact with others, which are in any kind of state of putrefaction or fermentation; their particles or atoms separate in a manner entirely analogous to the actual state of decomposition of the exciting body or ferment. Hence, one and the same substance may cause in solution of sugar the formation of several totally distinct series of compounds. In the first stage of the alteration produced in an animal membrane, by moistening it with water and exposing it to the air, it causes the conversion of sugar into lactic acid, gum, and mannite; in a subsequent stage, it causes the sugar to be resolved into alcohol and carbonic acid; and in a still later stage it resolves sugar into carbonic acid, butyric acid, and hydrogen gas.

The same substance which, in the juice of the beet-root, acting as a ferment, produces a true alcoholic fermentation, causes, in another period of its own decomposition, the resolution of sugar into gum, mannite, and lactic acid.

From all this it follows, that, to the different and manifold con-

ditions by which chemical forces are set in action, and their effects obtained, there must be added, as a new and powerful cause, the influence which a body, in the state of activity or motion, exerts on the condition and behavior of another body in contact with the first, or on the capacity of the atoms of this second body to arrange themselves in new groups, or to enter into combination with a third body, thus producing compounds which, without the assisting cause, would not have been formed under the given circumstances.

No one can deny that this cause is active, not only in the process of respiration, but also in all the processes going on in the animal body, in which it takes a certain share; and if by further investigation it should be established, that in the alcoholic fermentation the resolution of sugar into alcohol and carbonic acid depends on the development of inferior vegetables, in other words, that the transformation of a complex molecule and the formation of new compounds, can be effected in consequence of contact with certain particles which are in a state of vital activity, it is clear, that the path is opened up which will lead to an insight into the enigmatical processes of nutrition and secretion.

is active in respiration,

Every particle and constituent of the body is in a state of activity peculiar to itself, which is observed in its effects, in the phenomena of formation, decomposition or transformation. All parts produce and reproduce each other out of one and the same liquid, that is, out of blood, in consequence of the same activity. The elements of the blood behave, in contact with the parts of the body, as if they were elements of the latter; they enter into combinations, or arrange themselves, or separate into new groups, forming new products, according to the actual state or stage of change of the active body by which they are affected.

and in all organic processes.

In all these phenomena, one cause is in action; and it is unquestionably to be looked on as a proof of progress in the present time, that this cause has been recognized as one operating very generally in a vast number of chemical processes, both of combination and decomposition.

2

VI.

The want of a just conception of force and effect, and of the connection of natural phenomena, has led chemists to attribute a part of the heat generated in the animal body to the action of the nervous system. If this view exclude chemical action, or changes in the arrangement of the elementary particles, as a condition of nervous agency, it means nothing else than to derive the presence of motion, the manifestation of a force, from nothing. But no force, no power can come of nothing.

Influence of the nervous apparatus.

No one will seriously deny the share which the nervous apparatus has in the respiratory process; for no change of condition can occur in the body without the nerves. Under their influence, the viscera produce those compounds, which serve for the production of the animal heat; by the nerves these substances acquire the form and the properties, in virtue of which they are capable of combining with oxygen in a given time; and when the nerves cease to perform their functions, the whole process of the action of oxygen must assume another form.

Examples.

If we divide the medulla oblongata in two animals, and keep up respiration and the circulation of the blood and pulsations of the heart in one by blowing air into the lungs, while we observe the cooling in both, the temperature of the animal in whom artificial respiration is kept up is found for a time permanently higher, although by the change of air in the lungs evaporation and consequently cooling must have been accelerated. The temperature of both, however, sinks. But without reference to the imperfection of such experiments, this result is easily explained.

Explanation.

If the combination of the oxygen of the air with the elements of the blood were the only cause of the development of heat in the animal body, the temperature of the blood in these experiments could not fall; nay, by merely agitating the blood with oxygen, we should be able to produce and keep up a high temperature. The only difference would be that, in one case, the experiment would be made in a glass vessel, in the other

it would be made in the blood-vessel. But only one condition is here fulfilled, namely, the supply of oxygen: for the oxygen on its course does not find the substances with which it would, in the normal state, have combined, in the proper form: and on this, as the experiments show, the nervous system has a most decided influence. By the absorption of oxygen into the blood, in the experiment, a certain amount of heat was set free, but far less than the animal lost in the same time by cooling and evaporation; the conversion of oxygen into the normal oxidized compounds was prevented.

Analogous effect of the nerves in digestion.

As by the division of the pneumogastric nerves the motion of the stomach and the secretion of the gastric juice are arrested, and an immediate check is thus given to the process of digestion, so the paralysis of the organs of vital motion in the abdominal viscera affects the process of respiration. These processes are most intimately connected; and every disturbance of the nervous system, or of the nerves of digestion, re-acts visibly on the process of respiration.

The contraction of muscles produces heat.

The observation has been made, that heat is produced by the contraction of the muscles, just as in a piece of caoutchouc, which, when rapidly drawn out, forcibly contracts again, with disengagement of heat. Some have gone so far as to ascribe a part of the animal heat to the mechanical motions of the body, as if these motions could exist without a certain expenditure of force consumed in producing them; how, then, we may ask, is this force produced?

By the combustion of carbon, by the solution of a metal in an acid, by the combination of the two electricities, positive and negative, and even by the rubbing of two solid bodies together with a certain degree of rapidity, heat may be produced.

Various causes produce the same effect.

By a number of causes, in their manifestation entirely distinct, we can thus produce one and the same effect. In combustion, and in the production of galvanic electricity, we have a change of condition in material particles; when heat is produced by friction, we have the conversion of one kind of motion into another, which affects our senses differently. In all such cases we have a something given which merely takes another form; in all we have a force and its effect.

By means of the fire which heats the boiler of a steam-engine, we can produce every kind of motion, and by a certain amount of motion we can produce fire.

When we rub a piece of sugar briskly on an iron grater, it undergoes, at the surfaces of contact, the same change as if exposed to heat; and two pieces of ice, when rubbed together, melt at the point of contact.

Let us remember, that the most distinguished authorities in physics consider the phenomena of heat as phenomena of motion, because the very conception of the *creation* of matter, even though imponderable, is absolutely irreconcilable with its production by mechanical causes, such as friction or motion.

But, admitting all the influence which electric or magnetic currents in the animal body can have on the functions of its organs, still the ultimate cause of all these forces is a change of condition in material particles, which may be expressed by the conversion, within a certain time, of the elements of the food into oxidized products. Such of these elements as do not undergo this process of slow combustion, are given off unburned or incombustible in the excrements.

Now, it is absolutely impossible that a given amount of carbon or hydrogen, whatever different forms they may assume in the progress of the combustion, can produce more heat than than if directly burned in atmospheric air or in oxygen gas.

When we kindle a fire under a steam-engine, and employ the power obtained to produce heat by friction, it is impossible that the heat thus obtained can ever be greater than that which was required to heat the boiler; and if we use the galvanic current to produce heat, the amount of heat obtained is never, in any circumstances, greater than we might have by the combustion of the zinc which has been dissolved in the acid.

The contraction of muscles produces heat; but the force necessary for the contraction has manifested itself through the organs of motion, in which it has been excited by chemical changes. The ultimate cause of the heat produced is therefore to be found in these chemical changes.

By dissolving a metal in an acid, we produce an electrical current; this current, if passed through a wire, converts the wire

into a magnet, by means of which many different effects may be produced. The cause of these phenomena is magnetism; the cause of the magnetic phenomena is to be found in the electrical current; and the ultimate cause of the electrical current is found to be a chemical change, a chemical action.

There are various causes by which force or motion may be produced. A bent spring, a current of air, the fall of water, fire applied to a boiler, the solution of a metal in an acid,—all these different causes of motion may be made to produce the same effect. But in the animal body we recognize as the ultimate cause of all force only one cause, the chemical action which the elements of the food and the oxygen of the air mutually exercise on each other. The only *known* ultimate cause of vital force, either in animals or in plants, is a chemical process. If this be excluded, the phenomena of life do not manifest themselves, or they cease to be recognizable by our senses. If the chemical action be impeded, the vital phenomena must take new forms.

The heat produced by the combustion of carbon,

According to the corrected experiments of Dulong (6) on the amount of heat disengaged during the conversion of carbon into carbonic acid, it appears, that under these circumstances the temperature of 8558 parts, by weight, of water is raised, by the combustion of one part of carbon, from 32° to 33·8° F. (from 0° to 1° C.), so that 1 oz. of carbon during its combustion gives out so much heat as would melt 108⅓ oz. of ice, or raise that weight of water from 32° to 142° F. (0° to 79° C.).

the consumption of carbon;

The $13\frac{2}{10}$ oz. of carbon which are daily converted into carbonic acid in the body of a soldier, give out, consequently, as much heat as would suffice to heat 74⅓ lbs. of water from 32° to the boiling point, or to dissipate in vapor $11\frac{3}{10}$ lbs. of water.

If we now assume, that the evaporation through skin and lungs amounts, in 24 hours, to 48 oz., or 3 lbs., then there will remain, after deducting the necessary amount of heat, as much heat as would suffice daily to raise the temperature of 143 lbs. of water from the freezing point, 32°, to 98·5°, the temperature of the body.

the heat given out in the combustion of hydrogen, and the consumption of hydrogen, explain the constant temperature of the body.

If we now reflect, that 1 litre (about 61 cubic inches of oxygen gas, during its combination with hydrogen to form water, gives out, on an average, 6228 degrees of heat, while the same volume of oxygen, in being converted into carbonic acid only gives 4624 degrees of heat; if it cannot be denied, that the tenth part of the oxygen inspired by herbivorous animals, and the half of that inspired by carnivorous animals, is converted into water and not into carbonic acid; if we take into the calculation the heat thus produced; if, finally, we bear in mind that the specific heat of bones, of fat, and of the mass of the body, is much less than that of water, and that these bodies consequently require to be warmed to 98°, much less heat than an equal weight of water, it cannot be doubted that, all these considerations being attended to, the heat produced by the process of combustion going on in the body is fully sufficient to explain both the continual evaporation from the body, and its constant high temperature.

The determination of the carbonic acid alone, without

Experiments, in which the quantity of carbonic acid expired by a man in a given time has been measured, have shown, that an adult man, on the average, gives out to the atmosphere, in the form of carbonic acid, from 154 to 170 grains of carbon per hour. Supposing the proportions to continue unchanged for 24 hours, the daily consumption of carbon, in the individual experimented on, would be from 8 to 8½ oz. of carbon. But we cannot even with any certainty deduce, from the amount of carbonic acid expired during the short period of the experiment, the total quantity of carbonic acid expired in 24 hours, because the state of the body varies within the given time; and far less can we estimate, from that observation, how much oxygen the individual consumes on the whole. According to the observations hitherto made, the amount of expired carbonic acid is greater in the waking than in the sleeping state; the external temperature and density of the atmosphere, the quality of the food, and the different states of hunger or repletion, as well as exercise and bodily efforts, all these exert a very decided influence on the consumption of oxygen in the respiratory process, and cause a continual variation in the amount of expired carbonic

acid. The prisoners in the Bridewell at Marienschloss, where labor is enforced, consume in their food, in keeping up the process of respiration, not more than 10½ oz. of carbon. Those in the house of Arrest, at Giessen, who are deprived of all exercise, do not consume more than 8½ oz.; and in a family known to me, 9 persons, four children and five adults, did on an average consume more than 9½ oz. of carbon.

attending to other points, is useless for physiology.

VII.

If we designate the production of force in the animal body, as *motion* and *nervous life*, and the resistance, the condition of static equilibrium, as *vegetative life*; it is obvious that in all classes of animals the latter, namely vegetative life, prevails over the former, nervous life, in the earlier stages of existence.

Nervous life.

The passage or change of matter from a state of motion to a state of rest appears in an increase of the mass, and in the supply of waste; while the motion itself, or the production of force, appears in the shape of waste of matter.

In a young animal, the waste is less than the increase; and the female retains, up to a certain age, this peculiar condition of a more intense vegetative life. This condition does not cease in the female as in the male, with the complete development of all the organs of the body.

Waste less in young than in adult animals.

The female, as, for example, in the human species, is, at certain periods, capable of reproduction of the species. Partly under certain external conditions, such as temperature and food, partly from less-known causes which recur more or less periodically, the vegetative life in her organism is rendered more intense, and produces more than is wasted. The result is seen in the capacity of reproduction. Infinite wisdom has given to the female body the power, up to a certain age, of producing all the constituents of her organization in greater quantity than is required for the supply of the daily waste of the tissues. When this excess of production is not employed in the

Also in the female.

formation of a new being, it is periodically expelled from the system. This periodical discharge ceases as soon as the ovium has been impregnated; and from this time every drop of the superabundant blood goes to form an organism like that of the mother.

Exercise and labor cause a diminution in the quantity of the menstrual discharge; and when it is suppressed in consequence of disease, the vegetative life is manifested in a morbid production of fat. When the equilibrium between the vegetative and nervous life is disturbed in the male, when, as in eunuchs, the intensity of the latter is diminished, the predominance of the form is shown in the same form, in an increased deposit of fat.

VIII.

Explanation and definition of the term *food.*

If we hold, that the increase of mass in the animal body, the development of its organs, and the supply of waste,—that all this is dependent on the blood, that is, on the ingredients of the blood, then only those substances can properly be called nutritious or considered as food which are capable of conversion into blood. To determine, therefore, what substances are capable of affording nourishment, it is only necessary to ascertain the composition of the food, and compare it with that of the ingredients of the blood.

The blood.

The blood which circulates in the animal body appears under the microscope as a mechanical mixture of solid, translucent, disk-shaped corpuscules, of a red color, which swim in a colorless, or pale yellowish-brown transparent liquid.

Two substances require especial consideration as the chief ingredients of the blood; one of these separates immediately from the blood when withdrawn from the circulation. It is well known that in this case blood coagulates, and separates into a yellowish liquid, the *serum* of the blood, and a gelatinous mass, the clot, which is a network of fine colorless, translucent threads, inclosing the blood corpuscules. The substance of these threads is the *Fibrine* of the blood.

Fibrine.

If the blood, during coagulation, be beaten or whipped with a rod, no clot is formed; the fine threads of Fibrine, which mechan-

ically inclose the blood corpuscules, are torn and divided, and adhere together in coarse, soft, elastic masses, while the blood corpuscules remain floating in the serum, to which they give their peculiar color.

The muscular fibre, when purified from all other substances, is, in its properties and its composition, identical with the Fibrine of the blood.

The second principal ingredient of the blood is contained in the serum, and gives to this liquid all the properties of the white of eggs, with which it is identical. When heated, it coagulates into a white elastic mass, and the coagulating substance is called *Albumen*.

Albumen.

Fibrine and Albumen, the chief constituents of the blood, are distinguished from all other organic substances by containing sulphur. They contain, in all, seven elements, namely, Sulphur, Carbon, Nitrogen, Hydrogen, Oxygen, Phosphorus (as phosphoric acid), and Calcium (as lime). In the serum are found sea salt, and salts of Potash and Soda dissolved; these bases are combined with carbonic, phosphoric, and sulphuric acids. The blood globules or corpuscules contain Fibrine and Albumen, and also a red coloring matter, of which iron is an essential element. Besides these, the blood contains certain fatty bodies in small quantities, which differ from ordinary fats in several of their properties.

Ultimate elements of the blood.

Coloring matter of the blood.

Chemical analysis has led to the remarkable result, that Fibrine and Albumen contain the same organic elements united in the same proportion, so that two analyses, the one of Fibrine and the other of Albumen, do not differ more than two analyses of Fibrine or two of Albumen respectively do, in the composition of 100 parts.

Fibrine and Albumen are essentially identical.

In these two ingredients of blood the particles are arranged in a different order, as is shown by the difference of their external properties; but in chemical composition, in the ultimate proportion of the organic elements, they are identical.

This conclusion has lately been beautifully confirmed by a distinguished physiologist (Dénis), who has succeeded in converting Fibrine into Albumen, that is, in giving it the

Their mutual relations.

solubility, and coagulability by heat, which characterize the white of egg.*

When Fibrine is covered with ten times its volume of water, to which $\frac{1}{2000}$th part of hydrochloric acid has been added, it swells up, in a warm place, to a thick jelly, which, if the action of heat be continued, becomes entirely liquid. A small quantity of sea salt, nitre, or Glauber salt, causes this solution to coagulate into a white mass, very similar to coagulated albumen, or to cheese.

Fibrine and Albumen, besides having the same composition, agree also in this, that both dissolve in concentrated muriatic acid, with access of air, yielding a solution of an intense purple color. This solution, whether made with Fibrine or Albumen, has the very same re-actions with all the substances yet tried.

General view of the composition of the animal tissues.

When we compare the composition of all the animal tissues with that of the sulphurized and nitrogenized compounds circulating in all parts of the body, that is, with Fibrine and Albumen, the following relations are observed.

Some contain both sulphur and nitrogen.

Muscular fibre, the solid substance of the cartilage of the ear, nose, joints, and ribs, as well as that of the bones of young animals previous to ossification, also the solid substance of hair and horn, and among the fluids of the body, the bile, all these contain sulphur.

Some only nitrogen.

All the above, as well as membranes, nervous matter, and cellular tissue, with the saliva and the seminal fluid, contain nitrogen.

Proportion of the nitrogen to the carbon.

The chief constituents of the blood contain, for 1 equivalent of nitrogen, 8 equivalents of carbon. No part of the body, having an organized or peculiar form, contains, for 8 equivalents of carbon, less than 1 of nitrogen.

The most decisive experiments and observations have proved, that the animal organism is absolutely incapable of producing or creating an elementary body, such as sulphur, carbon, or nitrogen, out of substances which do not contain them. It obviously follows, therefore, that all kinds of food, fit for the production of

* The chemical characters of animal fibrine, albumen, and caseine, and their mutual relations to each other, are described with great care and accuracy in Dr. Jos. Scherer's very important treatise, published in the "Annalen der Chemie und Pharmacie," vol. xl. p. 1, et seq.

blood, must contain sulphur and nitrogen; and that those which can contribute to the formation of cells or of membranes, must, at all events, contain a certain proportion of nitrogen.

Substance of the brain and nerves.

The substance of the brain and nerves contains a large quantity of albumen, and, in addition to this, two peculiar fatty acids, distinguished from other fats by containing phosphorus (phosphoric acid ?). One of these contains nitrogen. (Frémy.)

Animal products containing no nitrogen.

Finally, water and common fat are those ingredients of the body which are destitute of nitrogen. Both are amorphous, or unorganized, and only so far take part in the vital process as that their presence is required for the due performance of the vital functions. The never-failing inorganic constituents of the body are iron, lime, magnesia, common salt, and the alkalies.

IX.

Nutrition of carnivora;

The nutritive process in the carnivora is seen in its simplest form. This class of animals lives on the blood and flesh of the graminivora; but this blood and flesh is, in all its properties, identical with their own. Neither chemical nor physiological differences can be discovered.

The nutriment of carnivorous animals is derived originally from blood; in their stomach it becomes dissolved, and capable of reaching all other parts of the body; in its passage it is again converted into blood, and from this blood are reproduced all those parts of their organization which have undergone change or metamorphosis.

With the exception of hoofs, hair, feathers, and the earth of bones, every part of the food of carnivorous animals is capable of assimilation.

In a chemical sense, therefore, it may be said, that a carnivorous animal, in supporting the vital processes, consumes itself. That which serves for its nutrition is identical with those parts of its organization which are to be renewed.

of young animals.

Not less simple appears the nutrition of young animals, whose development and growth are made

dependent on the supply of a fluid, which is separated from the body of the mother in the form of *milk*.

Caseine of milk. Milk contains a sulphurized and nitrogenized constituent, the so-called Caseine, or cheesy matter, which by itself is hardly soluble in water, but by the action of alkalies, and of many phosphates, acquires an extraordinary solubility. In milk, Caseine is combined with these substances, and thus that fluid has a weak alkaline reaction. In this state of combination, Caseine is distinguished from Albumen by its not coagulating when heated; when milk is boiled or evaporated, Caseine separates in the form of the well-known skin of milk, at the surface of the liquid, and the addition of acids, or of alcohol, separates the Caseine as a white coagulum. Besides Caseine, milk does not contain any other sulphurized and nitrogenized compound.

Composition of caseine. The chemical study of Caseine has shown that this body also is identical in composition with the chief constituents of blood, that is, with Albumen and Fibrine.

The young animal consequently receives, in the Caseine, the blood of the mother, at least as far as its chief constituents are concerned: for its conversion into Albumen and Fibrine, no third substance is required, and none of the organic elements of these two bodies separate from them in the organism of the mother, when they are converted into Caseine.

The Caseine of milk contains, chemically combined, a large quantity of bone earth in a dissolved form, which is consequently capable of being carried to all parts of the body. Milk is, moreover, invariably found to contain iron.

Thus, even in the earliest periods of its existence, we see that the formation and development of the organs in which vital activity is to reside, is connected, in the young animal, with the supply of a fluid, the chief constituent of which is a body similar, or rather identical in composition with the chief constituents of its blood.

Nutrition of herbivora. At first sight, the nutritive process in adult herbivorous animals appears to be quite different; their food consists of vegetables, which, as far as their chief mass is concerned, have no similarity to the food of the carnivora.

Whence, and from what substances, we may ask, is derived, in

the latter class of animals, the blood, out of which their organs are developed?

This question may be answered with sufficient certainty.

Chemical researches have shown, that all such parts of vegetables as can afford nutriment to animals contain certain constituents which are rich in sulphur and nitrogen; and the most ordinary experience proves that animals require for their support and nutrition less of these parts of plants in proportion as they abound in the sulphurized and nitrogenized constituents. Animals cannot be fed on matters destitute of these nitrogenized constituents.

Their food.

These important products of vegetation are especially abundant in the seeds of the different kinds of grain, and of pease, beans, and lentils; in roots, and in the juices of what are commonly called garden vegetables. They exist, however, in all plants, without exception, and in every part of plants, in larger or smaller quantity.

Constituents of their food.

These sulphurized and nitrogenized forms of nutriment in the vegetable kingdom may be reduced to three substances, which are easily distinguished by their origin.

When the newly-expressed juices of vegetables are allowed to stand, a separation takes place in a few minutes. A gelatinous precipitate, commonly of a green tinge, is deposited, and this, when acted on by liquids which remove the coloring matter, leaves a grayish-white substance, well known to druggists as the deposit from vegetable juices. This is one of the nitrogenized compounds which serves for the nutrition of animals, and has been named *vegetable Fibrine*. The juice of grasses is especially rich in this constituent, but it is most abundant in the seeds of wheat, and of the cerealia generally. It may be obtained from wheat flour by a mechanical operation, and in a state of tolerable purity; it is then called *Gluten*, but the glutinous property belongs, not to vegetable fibrine, but to a foreign substance, present in small quantity, which is not found in the other cerealia.

Vegetable fibrine, or gluten.

The method by which it is obtained sufficiently proves that it is insoluble in water; although we cannot doubt that it was originally dissolved in the vegetable juice, from which it afterwards separated, exactly as fibrine does from blood.

Vegetable albumen.

The second sulphurized and nitrogenized compound remains dissolved in the juice after the separation of the fibrine. It does not separate from the juice at the ordinary temperature, but is instantly coagulated when the liquid containing it is heated to the boiling point.

When the clarified juice of nutritious vegetables, such as cauliflower, asparagus, mangel wurzel, or turnips, is made to boil, a coagulum is formed, which it is absolutely impossible to distinguish from the substance which separates as a coagulum, when the serum of blood or the white of an egg, diluted with water, is heated to the boiling point. This is *vegetable Albumen.* A substance of very similar properties, but of somewhat different composition, is found in the greatest abundance in certain seeds, in nuts, almonds, and others in which the starch of the gramineæ is replaced by oil.

Vegetable caseine.

The third nitrogenized constituent of the vegetable food of animals is *vegetable Caseine.** It is chiefly found in the seeds of pease, beans, lentils, and similar leguminous seeds.

If we rub down pease or beans, after softening them in water, to thin paste, dilute this with water, and pass the mixture through a fine sieve, the husks are separated, and the strained liquid contains starch suspended, giving it a milky aspect, which starch is, however, soon deposited on standing. If the supernatant liquid be poured off, it continues to become turbid, and there now separates gradually a new precipitate in fine coherent flocculent masses, swollen up with moisture. In vegetable juices and leguminous seeds this body is combined with alkalies and salts with alkaline bases, to which it owes its solubility in water. By contact with the air, there is rapidly formed in these juices an acid, commonly lactic acid, which, neutralizing the alkali, causes the separation of the sulphurized and nitrogenized compound, which is, by itself, in-

* With regard to the name of *vegetable caseine*, Braconnot, its discoverer, observes, in his memoir on the caseine of milk (Ann. de Chim. et de Phys. xliii. p. 327), as follows: "I must here confess, that, in my examination of the seeds of the Leguminosæ, before I knew the properties of animal caseine, I may have fallen into an error, in describing, as a peculiar substance, legumine, a substance which now appears to me to be very analogous to caseine." The statement of Mulder, that vegetable caseine from pease contains no sulphur, is founded on an error.

soluble in water. The addition of acids causes the immediate separation of this substance from all the liquids in which it occurs dissolved. Tartaric and oxalic acids, in diluted solutions, re-dissolve the precipitate, and the addition of sulphuric or hydrochloric acids to these solutions causes a new precipitation.

The solution of vegetable Caseine, as obtained directly from pease or beans, does not coagulate when boiled, like the solution of vegetable Albumen; but on evaporation a skin forms on the surface of the liquid, as in the case of the Caseine of milk.

The sulphurized and nitrogenized constituents of the juices and seeds of plants never, or at least very rarely, occur alone. Thus the juice of potatoes contains, besides Albumen, Caseine precipitable by acids; and in the seeds of leguminous plants, as well as of the cereals, Albumen, coagulable by heat, is always present, along with Caseine in the one case, and what is called vegetable Fibrine in the other.*

Composition of these substances.

Chemical investigations have established as a rule without exception, that the food of the graminivorous animal always contains one or the other of these sulphurized and nitrogenized compounds. It appears that if these be excluded no other food can keep up in these animals the vital process. In the numerous other nitrogenized compounds occurring in the vegetable kingdom, such as the active principles of poisonous and medicinal plants, the sulphur is wanting; and the acrid, irritating, sulphurized compounds found in many seeds, bulbs, and roots, either are not used as food by animals, or, in their natural shape, take no share in the formation of blood.

They have the same composition,

The chemical analysis of these three substances has led to the very interesting result that they contain the same organic elements, united in the same proportion

* I am very doubtful whether the vegetable Fibrine contained in the Gluten of wheat can be viewed as a distinct substance. When flour is acted on by diluted sulphuric acid, with the aid of heat, till all the starch is converted into sugar, the Gluten is left in a form not distinguishable from vegetable Caseine. The products of its putrefaction also, including the so-called caseous oxide, are identical with those of cheese. Wheat, as is well known, contains monobasic alkaline phosphates; pease and beans, on the contrary, contain tribasic alkaline phosphates; the former has an acid reaction, the latter an alkaline one, which may perhaps explain the insolubility of the Caseine in wheat, and its solubility in the seeds of leguminous plants.

by weight; and, what is still more remarkable, that they are identical in composition with the chief constituents of blood, animal Fibrine, and Albumen. They all three dissolve in concentrated muriatic acid with the same deep purple color, and even in their physical characters, animal Fibrine and Albumen are in no respect different from vegetable Fibrine and Albumen.

and are identical with the constituents of blood.

Characters.

When the solution of animal Fibrine, Albumen, or Caseine in caustic potash is boiled for a long time, the addition of an acid in excess produces, in all three, a disengagement of sulphuretted hydrogen. The addition of a drop of solution of acetate of lead to the alkaline liquid causes a black precipitate of sulphuret of lead. Vegetable Caseine and Albumen exhibit precisely the same characters.

The presence, in vegetable food, of matters identical in composition with Fibrine and Albumen, the chief constituents of the blood, is not the only condition necessary for the production of blood. It has been mentioned that iron is a never-failing element of the blood corpuscules, and we find, moreover, in Fibrine, Albumen, and Caseine a certain quantity of phosphate of lime, or bone-earth. The blood itself is a slightly alkaline fluid, containing sea salt and salts of the alkaline bases, especially alkaline phosphates, to the presence of which the blood is indebted for its peculiar properties.*

Iron in vegetables.

* The absence of alkaline carbonates in the blood (of the ox) appears from the following observations. If 3 or 4 lbs. of blood be mixed with an equal weight of water, the mixture heated to boiling, and the coagulum strongly pressed out, there is obtained a clear greenish fluid, having an alkaline reaction. If the blood contained alkaline carbonates, they would necessarily be present in this fluid and discoverable there. If now the liquid be evaporated to a small volume in a retort, and the residue placed in contact with carbonic acid gas over mercury, it absorbs 3 or 4 times its volume of the gas. Now if this absorption depended on the presence of alkaline carbonates, which had passed into the state of bicarbonates, then the same volume of the original concentrated liquid must yield, when supersaturated with an acid, in the same apparatus, 3 or 4 times its volume of carbonic acid gas. But experiment shows, that by the addition of acid in excess, no appreciable quantity of gas is disengaged; and further investigation proves that the alkaline reaction of the liquid, and its power of absorbing carbonic acid gas is derived from the presence of phosphate of soda.

Phosphates in vegetable food necessary for the formation of blood.

Now the examination of those parts of vegetables, which, like the seeds of the cereals, or like pease, beans, and lentils, are rich in the sulphurized and nitrogenized constituents, which serve to produce blood, has shown that they contain the same incombustible elements (or ashes) as the blood; and it has been established, that the amount of these constituents of blood in any part of a vegetable stands in a most direct relation to the quantity of phosphates in that same part of the plant. Seeds, which, like pease and beans, are especially rich in the constituents of blood, contain a very decidedly larger quantity of alkaline and earthy phosphates, (phosphates of lime and magnesia,) than wheat does, and wheat more than rye. In these seeds no organic acid is found to be combined with the alkalies; they leave, after being burned, no carbonates, and their ashes, in this respect, agree entirely with those of the blood.

Phosphates also necessary to vegetable life.

The experience of agriculturists points out that in vegetables the production of the sulphurized and nitrogenized constituents of their seeds and juices, is most closely connected with the presence of phosphates.

When alkaline or earthy phosphates are wanting in the soil, or when they are not introduced in the form of manure, the seeds are not developed. If we suppose the other conditions of vegetable life to be given, then, from the experience hitherto acquired, we may draw this conclusion, that the development of plants, and the amount of the constituents of blood they contain, are directly proportional to the quantity of phosphates supplied to them and taken up by them.

From the less complex compounds which the vivified germ of the plant requires for its development, to the more complex combinations out of which the animal organism is produced, we see an unbroken chain of conditions; phosphates, so necessary to the formation of blood, and to all animal life, are no less essential to the existence and to the propagation of all vegetable beings.

It has been mentioned that Dénis has succeeded in converting animal Fibrine (from venous blood), by digestion with a solution of nitre in a warm place into a solution coagulable by heat exactly like the serum of blood. A similar conversion of the Fibrine of

blood into Albumen is observed when it is exposed to air and moisture, and thus allowed to putrefy; and it appears to be of essential significance for the process of nutrition in the herbivora, that the insoluble vegetable Fibrine in wheat or barley, as well as the vegetable Caseine in pease, &c., should be converted into soluble and coagulable Albumen, in consequence of the changes which these seeds undergo during germination.

Mutual dependence of animal and vegetable life.

How beautifully and admirably simple, with the aid of these discoveries, appears the process of nutrition in animals, the formation of their organs, in which vitality chiefly resides! Those vegetable principles, which in animals are used to form blood, contain the chief constituents of blood, Fibrine, and Albumen, ready formed, as far as regards their composition. All plants, besides, contain a certain quantity of iron, which re-appears in the coloring matter of the blood. Vegetable Fibrine and animal Fibrine, vegetable Albumen and animal Albumen hardly differ, even in form; if these principles be wanting in the food, the nutrition of the animal is arrested; and when they are present, the graminivorous animal obtains in its food the very same principles on the presence of which the nutrition of the carnivora entirely depends.

Vegetables produce in their organism the chief constituents of the blood of all animals; for the carnivora, in consuming the blood and flesh of the graminivora, consume, strictly speaking, only the vegetable principles which have served for the nutrition of the latter. Vegetable Fibrine and Albumen take the same form in the stomach of the graminivorous animal as animal Fibrine and Albumen do in that of the carnivorous animal.

From what has been said, it follows that the development of the animal organism and its growth are dependent on the reception of certain principles identical with the chief constituents of blood.

In this sense we may say that the animal organism gives to blood only its form; that it is incapable of creating blood out of other substances which do not already contain the chief constituents of that fluid. We cannot, indeed, maintain that the animal organism has no power to form other compounds, for we know that it is capable of producing an extensive series of compounds,

differing in composition from the chief constituents of blood; but these last, which form the starting point of the series, it does not produce for itself.

The animal body is a higher organism, the development of which begins with the most complex products of vegetable life; and among these, with substances, such as the constituents of seeds, with the production of which the life of an ordinary vegetable ends. As soon as the latter has borne seed, it dies, or a period of its life comes to a termination.

In that endless series of compounds, which begins with carbonic acid, ammonia, and water, the sources of the nutrition of vegetables, and includes the most complex constituents of the animal brain, there is no blank, no interruption. The first substance capable of affording nutriment to animals is a product of the creative energy of vegetables.

The substance of cellular tissue and of membranes, of the brain and nerves, these the vegetable cannot produce.

The seemingly miraculous in the productive agency of vegetables disappears in a great degree, when we reflect that the production of the constituents of blood cannot appear more surprising than the occurrence of the fat of beef and mutton in cocoa beans, of human fat in olive oil, of the principal ingredient of butter in palm oil, and of horse fat and train oil in certain oily seeds.

X.

The function of the non-nitrogenized constituents of food.

While the preceding considerations leave little or no doubt as to the way in which the increase of mass in an animal, that is, its growth, is carried on, there is yet to be resolved a most important question, namely, that of the function performed in the animal system by substances containing no nitrogen, such as sugar, starch, gum, pectine, &c.

No class of animals can live without these substances; their food must contain a certain amount of one or more of them, and if these compounds are not supplied, death quickly ensues.

The food of carnivorous animals always contains a certain proportion of *fat*, milk contains *butter* and *sugar of milk;* the roots,

herbs, seeds, and bulbs, which serve as food to graminivorous animals, contain *starch, sugar, gum,* or *pectine.*

What, now, is the purpose served by the fat, butter, sugar of milk, the starch, sugar, pectine, or gum. What is the reason why they are essential to the life of the young animal?

With the exception of the starch of grain, which contains a fraction of one per cent. of phosphate of lime, and of gum and pectine, which leave, after combustion, a certain quantity of alkaline ashes, sugar, fat, butter, sugar of milk, &c., contain no fixed bases, no lime, soda, nor potash. Sugar of milk has a composition analogous to that of ordinary sugar, of starch, and of gum. They all consist of carbon and the elements of water, and these last, indeed, exactly in the same proportion as in water.

There is added, therefore, by means of these compounds, to the nitrogenized constituents of food, a certain amount of carbon, or, as in the case of butter, of carbon and hydrogen; that is, an excess of elements, which cannot possibly be employed in the production of blood, because the nitrogenized substances contained in the food already contain exactly the amount of carbon which is required for the production of Fibrine and Albumen.

They serve for respiration.

The following considerations will show that hardly a doubt can be entertained, that this excess of carbon alone, or of carbon and hydrogen, is expended in the production of animal heat, and serves to protect the organism from the external action of the atmospheric oxygen.

XI.

Change of matter in the carnivora.

In order to obtain a clearer insight into the nature of the nutritive process in both the great classes of animals, let us first consider the changes which the sulphurized and nitrogenized constituents of the food of the carnivora undergo in their organism.

If we give to an adult serpent, or boa constrictor, a goat, a rabbit, or a bird, we find that the hair, hoofs, horns, feathers, or bones of these animals, are expelled from the body apparently unchanged. They have retained their natural form and aspect, but have become

brittle, because of all their component parts they have lost only that one which was capable of solution, namely, the gelatine.

We find, moreover, that, when the serpent has regained its original weight, every other part of its prey, the flesh, the blood, the brain, and nerves, in short, every thing, has disappeared.

Uric acid.

The chief excrement is a substance expelled by the urinary passage. When dry, it is pure white, like chalk; it contains much nitrogen, and a small quantity of carbonate and phosphate of lime mixed with the mass.

We find the sulphur of the sulphurized and nitrogenized constituents of the food in the urine in the form of sulphuric acid, that is, as an oxidized product.

The excrement above mentioned is urate of ammonia, a chemical compound, in which the nitrogen bears to the carbon the same proportion as in bicarbonate of ammonia. For every equivalent of nitrogen, it contains two equivalents of carbon.

But muscular fibre, blood, membranes, and skin, contained four times as much carbon for the same amount of nitrogen, or eight equivalents to one; and if we add to this the carbon of the fat and nervous substance, it is obvious that the serpent has consumed, for every equivalent of nitrogen, much more than eight equivalents of carbon.

If we now assume that the urate of ammonia contains all the nitrogen of the animal consumed, then at least six equivalents of carbon, which were in combination with this nitrogen, must have been given out in a different form from the two equivalents which are found in the urate of ammonia.

Now we know, with perfect certainty, that this carbon has been given out through the skin and lungs, which could only take place in the form of an oxidized product.

The excrements of a buzzard which had been fed with beef, when taken out of the rectum, consisted, according to L. Gmelin and Tiedemann, of urate of ammonia. In like manner, the fæces in lions and tigers are scanty and dry, consisting chiefly of bone-earth, with mere traces of compounds containing carbon; but their urine contains, not urate of ammonia, but urea, a compound in which carbon and nitrogen are to each other in the same ratio as in *neutral* carbonate of ammonia.

Assuming that their food (flesh, &c.) contains carbon and nitrogen in the ratio of eight equivalents to one, we find these elements in their urine in the ratio of one equivalent to one; a smaller proportion of carbon, therefore, than in serpents, in which respiration is so much less active.

The whole of the carbon and hydrogen which the constituents of blood in the food of these animals contained, beyond the amount which we find in their excrements, has disappeared, in the process of respiration, as carbonic acid and water.

Had the animal food been burned in a furnace, the change produced in it would only have differed in the forms of combination assumed by the nitrogen from that which it underwent in the body of the animal. The nitrogen would have appeared, with part of the carbon and hydrogen, as carbonate of ammonia, while the rest of the carbon and hydrogen would have formed carbonic acid and water. The incombustible parts would have taken the form of ashes, and any part of the carbon unconsumed from a deficiency of oxygen would have appeared as soot, or lamp-black. Now the solid excrements are nothing else than the incombustible, or imperfectly burned, parts of the food.

In the preceding pages it has been assumed that the elements of the food are converted by the oxygen absorbed in the lungs into oxidized products; the carbon into carbonic acid, the hydrogen into water, and the nitrogen into a compound containing the same elements as carbonate of ammonia.

Waste and supply in an adult animal.

This is only true in appearance; the body, no doubt, after a certain time, acquires its original weight. The amount of carbon, and of the other elements, is not found to be increased—exactly as much carbon, hydrogen, and nitrogen has been given out as was supplied in the food; but nothing is more certain than that the carbon, hydrogen, and nitrogen given out, although equal in amount to what is supplied in that form, do not directly proceed from the food.

It would be utterly irrational to suppose that the necessity of taking food, or the satisfying the appetite, had no other object than the production of urea, uric acid, carbonic acid, and other excrementitious matters—of substances which the system expels, and consequently applies to no useful purpose in the economy.

In the adult animal, the food serves to restore the waste of matter; certain parts of its organs have lost the state of vitality, have been expelled from the substance of the organs, and have been metamorphosed into new combinations, which are amorphous and unorganized.

The food serves to supply the waste of the body,

The food of the carnivora is at once converted into blood; out of the newly-formed blood those parts of organs which have undergone metamorphoses are reproduced. The carbon and nitrogen of the food thus become constituent parts of organs.

and for the formation of blood.

Exactly as much sulphur, carbon, hydrogen and nitrogen is supplied to the organs by the blood, that is, ultimately, by the food, as they have lost by the transformations attending the exercise of their functions.

What, then, it may be asked, becomes of the new compounds produced by the transformations of the organs, of the muscles, of the membranes and cellular tissue of the nerves and brain?

These new compounds cannot, owing to their solubility, remain in the situation where they are formed, for a well-known force, namely, the circulation of the blood, opposes itself to this.

The dissolved products of transformation enter the circulation,

By the action of the heart, an organ in which two systems of canals meet, which branch out into an infinitely minute network of tubes, the fluid contained in these canals is set in motion towards one side of the heart; and a certain property, belonging to all such partitions, and especially organized ones, as are permeable to fluids, causes all substances dissolved in the fluids of the body to find their way into the system of canals or vessels, and to follow the motion of the blood.

This property is the following: namely, that the dissolved matters of two solutions, although separated by an animal membrane or by the walls of a cell, are nevertheless not thereby prevented from mutually mixing together. The constituents of one of the fluids thus separated may soon be detected in the other; but there is no mutual exchange of particles when the fluids contain the same substances in equal quantity. The passage of the fluids with their

in consequence of a physico-chemical property of membranes.

dissolved contents through the separating membrane is effected by an inequality in the nature and composition of the fluids.

The unequal degree in which fluids possess the property of moistening the walls of cells exerts a very decisive influence on the passage of these fluids, or the exchange of dissolved matter between them; and the share taken by chemical affinity in effecting this passage or exchange is not less important, since the amount of exchange towards one side or the other appears to be determined by that force. The power of moistening and the strength of affinity are both manifested in the form of an attraction, which in this case is best compared to a mechanical pressure.

All soluble substances act in the same way.

It is obvious that in consequence of these forces acting on them, all the animal fluids and the matters dissolved in them must be compelled to move towards the heart.

The taking up of dissolved foreign matters into the blood, or the absorption of such matters, is a chemico-mechanical act, which, as we have seen, extends to liquid substances of every kind, saline solutions, poisons, &c.

They move towards the heart.

It is now, therefore, obvious, that by the forcible entrance of arterial blood into the capillary vessels, the fluids contained in these,—in other words, the soluble compounds produced by the transformation of the organized tissues, must, as above stated, be compelled to move towards the heart.

They enter the veins.

These compounds cannot be employed for the reproduction of those tissues from which they are derived. They pass through the absorbent and lymphatic vessels into the veins, where their accumulation would speedily put a stop to the nutritive process, were it not that this accumulation is prevented by two contrivances adapted expressly to this purpose.

Pass through the liver and kidneys,

A part of the venous blood, before reaching the heart, is made to pass through the liver; a part of the arterial blood, on the other hand, passes through the kidneys, which separate from it all substances incapable of contributing to nutrition.

Of the newly produced compounds, some are collected in the urinary bladder; another part is separated by the liver in the form of *Bile*.

and are given out in the form of bile and urine.

Physiologists cannot entertain any doubt as to the origin of the constituents of the Urine and of the Bile. Even when all food is withheld, the secretion of bile takes place; in the bodies of those who have been starved to death, the gall-bladder is found distended and full of bile.

Bile and urine secreted during starvation.

The secretion of bile and of urine goes on during the winter sleep of hybernating animals; and we know that the urine of dogs, fed for three weeks exclusively on pure sugar, contains as much of the most highly nitrogenized constituent, urea, as in the normal condition. (Marchand. Erdmann's Journal für praktische Chemie, XIV. p. 495.)

The urine of the mammalia, of birds, and of amphibia, contains uric acid, or urea; and the excrements of the mollusca, and of insects, as of cantharides and of the butterfly of the silkworm, contain urate of ammonia.

Urea, uric acid, and ammonia are compounds of nitrogen; all living animal parts contain nitrogen.

The chief constituent of bile contains *sulphur* and nitrogen; with the exception of membranes and of cellular tissue, every part of the body contains sulphur.*

It is obvious that the constituents of the urine, as well as the chief constituents of the bile, are products of the transformation of the blood and of the organized tissues. The elements of urea, uric acid, and bile were previously constituent elements of the living tissues, which have lost the condition of life in the vital process by the action of external causes.

We know, with certainty, therefore, that some of the nitrogenized compounds, produced by the metamorphosis of organized tis-

* *Note by the Editor.*—In a recent communication from Professor Liebig, dated subsequent to the printing of the above in the original, he informs the Editor that not only albumen, fibrine, and caseine, have been found in the Laboratory at Giessen, to contain more sulphur than is commonly admitted, albumen containing about 2 per cent., but that gelatine) that is, membrane and cellular tissue, or at least the substance extracted from them by boiling with water), contains ½ per cent. of sulphur.—W. G.

sues, after being separated from the arterial blood by means of the kidneys, are expelled from the body as utterly incapable of further alteration.

But another nitrogenized chief product, in which we find the sulphur of the transformed tissues, and which is peculiarly rich in carbon, returns, as bile, during the process of digestion, into the system, in which it gradually disappears, partially or entirely.

Bile is an element of respiration.

If we compare the composition of the bile with the nature and composition of the substances which are expelled through the intestinal canal, it evidently appears, that the combustible elements of the bile, without referring to the important part which that fluid plays in the process of digestion, ultimately leave the body in the shape of oxidized compounds, and are perfectly capable of being employed in respiration.

Bile contains carbonate of soda.

The bile contains sulphur, and is a compound of soda.

Fæces contain no carbonate of soda.

The fæces of carnivorous animals, as of serpents and of dogs, fed with flesh and bones, contain a very small proportion of organic excretions, which promote the passage through the intestine of the substances not taken up during the digestive process. They consist chiefly of bone-earth, and when incinerated, yield only traces of soluble salts, among which, however, is not found carbonate of soda, which is left when bile is incinerated.

It is perfectly certain that the soda of the bile has again entered into the circulation.

We can form a tolerably exact idea of the extremely small proportion of organic matter contained in the fæces of hyenas and other carnivora, if we reflect on the fact, that the excrements of animals of that class (coprolites), which must have lived thousands of years ago, are still recognizable by their form.

We find the soda and sulphur of the bile, the first in the form of a salt of soda, the latter in the form of a sulphate, in the urine.

The peculiar property of the vessels of the intestinal canal, that of taking up and carrying into the blood soluble substances of every kind, provided these do not form an insoluble compound with the organic tissue of the vessels, is well known.

A solution of common salt (1 part of salt to 80 of water), administered as an enema, disappears in the great intestine just as pure water would do, without the proportion of salt in the fæcal evacuation an hour afterwards being in the smallest degree increased. But the proportion of salt in the urine increases in a direct proportion. In like manner, ferrocyanide of potassium, or iodide of potassium, introduced in the same way into the rectum, very soon appears in the urine; and the disappearance of an enema of bile in the rectum, while the bile cannot be detected in the urine, proves, not only the passage or return of the bile into the blood, but also its employment in the respiratory process.

Soluble salts pass into the urine; but bile does not.

If we consider the ultimate forms in which the food of the carnivora re-appears, it is certain that they are identical with the chief constituents of their bodies. The metamorphoses which their tissues undergo, must be identical with those which, in the vital process, occur in the food. The bile, urea, uric acid, ammonia, carbonic acid, a certain amount of water, all these are derived from the food: the constituents of the urine and of the bile are products of the metamorphosis of the nitrogenized and sulphurized constituents of the food.

The flesh and blood consumed as food ultimately yield the greater part of their carbon for the support of the respiratory process, while its nitrogen appears as urea or uric acid, its sulphur as sulphuric acid. But previously to these final changes, the dead flesh and blood become living flesh and blood, and it is, strictly speaking, the combustible elements of the compounds formed in the metamorphoses of living tissues, which, with some other substances, to be more particularly mentioned hereafter, serve for the production of animal heat.

The food of the carnivora is converted into blood, which is destined for the reproduction of organized tissues; and by means of the circulation a current of oxygen is conveyed to every part of the body. The globules of the blood, which in themselves can be shown to take no share in the nutritive process, serve to transport the oxygen, which they give up in their passage through the capillary vessels. Here the oxygen of the arterial blood enters into combination with the compounds produced by the transfor-

mation of the tissues, and a quantity, exactly corresponding to the amount of oxygen, separates from these compounds in the form of carbonic acid and water. The amount of available oxygen present in a given time, depends on the quantity which the blood has taken up in its passage through the lungs; and it is obviously not sufficient to convert the elements of the products of transformation at once into the most highly oxidized compounds.

As much of the products of transformation as remains unoxidized in a given time, is either expelled from the body in the form of urine, as incapable of further change, or returns into the system in the form of bile, to serve for peculiar processes, and at a subsequent time, in assuming its ultimate forms, to support respiration.

Without attempting in this place to exhaust the whole question of the share taken by the Bile in the vital operations, it follows, as has been observed, from the simple comparison of those parts of the food of the carnivora which are capable of assimilation, with the ultimate products into which they are converted, that all the carbon of the food, except that portion which is found in the Urine, is given out as carbonic acid.

XII.

Proportion of the consumption of oxygen to the food in adult animals.

It cannot be disputed, that in an *adult* carnivorous animal, which neither gains nor loses weight, perceptibly, from day to day, its nourishment, the waste of organized tissue, and its consumption of oxygen, stand to each other in a well-defined and fixed relation.

The carbon of the carbonic acid given off, with that of the urine; the nitrogen of the urine, and the hydrogen given off as ammonia and water; these elements, taken together, must be exactly equal in weight to the carbon, nitrogen, and hydrogen of the metamorphosed tissues; and since these last are exactly replaced by the food, to the carbon, nitrogen, and hydrogen of the food. Were this not the case, the weight of the animal could not possibly remain unchanged.

If we suppose the body of a carnivorous animal to consist of nothing else but the sulphurized and nitrogenized substances which we know as constituents of its tissues and of its blood, then it is quite certain, that, if all food be withheld, all the carbon which in the state of starvation is given off in the forms of carbonic acid, urea, or uric acid, and all the hydrogen which is expired in a given time as water or as ammonia, must have come from the blood or from the tissues. The continual diminution in weight and the emaciation of the body is a necessary consequence of the conversion of parts of the body into oxidized products and their expulsion from the body.

The loss of weight depends on the absorption of oxygen.

It is further certain, that in this case the heat developed has been produced by the conversion into carbonic acid and water of that part of the combustible elements of these portions of the body which have been given out through the skin and lungs; and of the conversion into uric acid and urea, which appear in the urine, of the residue of the carbon and hydrogen.

If we further assume that the contact of the oxygen conveyed by the blood is not of itself sufficient to put an end to the condition of vitality in the living tissues, and thus to change their composition, it is clear that the oxygen can only combine with the products of the transformations of these parts of the body. In this case the amount of elements ready to enter into combination with the oxygen is directly proportional to the amount of metamorphosed tissues.

If, on the other hand, we suppose that the force existing in the living tissues does not destroy the power of the oxygen conveyed to them by the blood, to combine with their combustible elements, then the substance of these tissues must undergo a change, inasmuch as it is converted into oxidized products. In this case, that is, in the absence of all other substances which can destroy the chemical action of the oxygen, or, in other words, which can combine with it, the amount of metamorphosis of tissue or change of matter in a given time stands in a definite proportion to the amount of oxygen taken up in the same time.

The consumption of oxygen bears a fixed ratio to the change of matter.

The change of matter and consumption of oxygen may be measured by the amount of nitrogen in the urine.

Uric acid and urea contain the nitrogen of the metamorphosed tissues: they are the final products of the change which the sulphurized and nitrogenized constituents of the body undergo in the vital process under the co-operation of oxygen. It is obvious that the amount of the nitrogenized constituents of the urine is directly proportional to that of the metamorphosed tissues.

XIII.

The fat in the food of the carnivora

In the preceding pages we have considered the changes which the sulphurized and nitrogenized constituents of the food undergo in the body with the aid of the oxygen of the atmosphere. But these are not the only substances, rich in carbon and hydrogen, which the animal body contains and which the carnivorous animal consumes.

Everywhere, and in all parts of the animal organism, there is found, in the form of fat, a substance which beyond all others is rich in the elements adapted for combination with oxygen.

disappears in the body,

When all food is withheld, fat, in the healthy body, disappears, and emaciation is first observed in those parts the form of which is determined by their supply of fat. Now since the fæces and urine in the natural state contain no fat, and we know of no other channel, besides these, through which the elements of fat can pass out of the body, except through the skin and lungs; and since the carbon given out by the skin and lungs, with the exception of the insignificant quantity of grease in the skin, can only be given out in the form of carbonic acid, the hydrogen only as water, it follows necessarily that in the animal body the constituents of fat are applicable to the respiratory process, and consequently to the production of animal heat.

and is given out in gaseous forms.

It contributes to the respiratory process.

In the normal condition of the nutritive process, the carnivorous animal consumes, like all other animals, more carbon and hydrogen than corresponds to the amount of those elements in the sulphurized and nitrogenized constituents of its food: and conse-

quently the amount of carbonic acid given out, and the amount of oxygen daily absorbed into the system, must exceed what is required by the carbon of the metamorphosed tissues to be converted into carbonic acid and the ultimate products of their metamorphosis.

This excess of carbon and hydrogen is contained in the food of the carnivora in the form of fat. The blood of animals contains fat, and muscle or flesh, freed from the visible particles of fat, contains in many cases, half the weight of the solid matter in the shape of fat. (Graham.)

It follows from this, that in the normal state of health, in an adult carnivorous animal, the weight of which does not perceptibly alter from day to day, the weight of the carbon and hydrogen given out in the form of carbonic acid and water is equal to the weight of these elements in the fat, added to the weight of the same elements in the metamorphosed tissues which, together, have been given out in the form of carbonic acid and water.

Conditions of uniformity of weight in the body.

If, therefore, the condition and proportional weight of all parts of the carnivorous animal are to remain unaltered, it must receive daily, in its food, a certain amount of sulphurized and nitrogenized constituents and of fat.

The weight of the constituents of blood given in the food must be equal to that of the constituents of blood given out in the forms of uric acid, urea, and carbonic acid.

The weight of the fat given in the food must be equal to that of the fat given out in the form of carbonic acid and water.

From all this it follows, that the consumption of oxygen in a given time can give no measure of the amount of tissues metamorphosed in that time.

The consumption of oxygen expresses the sum of two effects. The first is the conversion of the non-nitrogenized, the other the conversion of the nitrogenized constituents into oxidized products.

If, of these three values, two are known or ascertained, the third, unknown, value may be deduced. It has been already frequently mentioned, that the quantity of the sulphurized and nitrogenized constituents of the body which has been converted into oxidized compounds, may be measured, in the healthy state, by the amount of nitrogen contained in the urine.

The amount of non-nitrogenized substances in the food, which serve for the production of animal heat, as a condition of the increase of mass or growth, and as a means of diminishing the waste in the animal body, appears to be a necessity, when we consider the composition of that food which the organism itself provides for the young animal.

XIV.

The food of all animals contains substances devoid of nitrogen.

The milk of carnivorous animals contains, along with caseine (a compound from which the sulphurized and nitrogenized constituents of their blood are formed), fat; the milk of graminivorous animals contains both fat and sugar of milk, of which the latter entirely disappears in the body of the young animal.

In the adult graminivora we also observe, that, during their whole life, their existence depends on the supply of substances having a composition identical with that of sugar of milk, or closely resembling it. Every thing that they consume as food contains a certain quantity of starch, or gum, or sugar, mixed with other matters.

Occurrence of starch.

The most abundant and widely extended of the substances of this class is amylon or starch; it occurs in roots, seeds, and stalks, and even in wood, deposited in the form of roundish or oval globules, which differ from each other in size alone, being identical in chemical composition. (6) In the same plant, in the pea, for example, we find starch, the globules of which differ in size. Those in the expressed juice of the stalks have a diameter of from $\frac{1}{200}$ to $\frac{1}{150}$ of an inch, while those in the seed are three or four times larger. The globules in arrow-root and in potato-starch are distinguished by their large size; those of rice and of wheat are remarkably small.

Its conversion into sugar

It is well known that starch may be converted into sugar by very different means. This change occurs in the process of germination, as in malting, and it is easily accomplished by the action of acids. The metamorphosis of starch into sugar depends simply, as is proved by analysis, on the addi-

tion of the elements of water. (7) All the carbon of the starch is found in the sugar; none of its elements have been separated, and except the elements of water, no foreign element has been added to it in this transformation.

by the addition of the elements of water.

In many, especially in pulpy fruits, which, when unripe, are sour and rough to the taste, but when ripe are sweet, as for example, in apples and pears, the sugar is produced from the starch which the unripe fruit contains.

If we rub unripe apples or pears on a grater to a pulp, and wash this with cold water on a fine sieve, the turbid liquid which passes through deposits a very fine flour of starch, of which not even a trace can be detected in the ripe fruit. Many varieties become sweet while yet on the tree; these are the summer or early apples and pears. Others, again, become sweet only after having been kept for a certain period after gathering. The after-ripening, as this change is called, is a purely chemical process, entirely independent of the vitality of the plant. When vegetation ceases, the fruit is capable of reproducing the species, that is, the kernel, stone, or true seed is fully ripe, but the fleshy covering from this period is subjected to the action of the atmosphere. Like all substances in a state of eremacausis, or decay, it absorbs oxygen, and gives off a certain quantity of carbonic acid gas.

This change during the maturation of fruits.

In the same way as the starch in putrefying paste in which it is in contact with decaying gluten, is converted into sugar, the starch in the above-named fruits, in a state of decay, or eremacausis, is transformed into grape sugar. The more starch the unripe fruit contains, the sweeter does it become when ripe.

A close connection thus exists between sugar and starch. By means of a variety of chemical actions, which exert no other influence on the elements of starch than that of changing the direction of their mutual attraction, we can convert starch into sugar, but it is always grape sugar.

Sugar of milk in many respects resembles starch; (8) it is, by itself, incapable of the vinous fermentation, but it acquires the property of resolving itself into alcohol and carbonic acid when it is exposed to heat in contact with a substance in the state of fermentation (such as putrefying cheese in milk).

Sugar of milk

In this case, it is first converted into grape sugar; and it undergoes the same transformation when it is kept in contact with acids—with sulphuric acid, for example—at the ordinary temperature.

and gum Gum has the same composition in 100 parts as cane sugar. (9) It is distinguished from the different varieties of sugar by its not possessing the property of being resolved into alcohol and carbonic acid by the process of putrefaction. When placed in contact with fermenting substances, it undergoes no appreciable change, whence we may conclude, with some degree of probability, that its elements, in the peculiar arrangement according to which they are united, are held together with a stronger force than the elements of the different kinds of sugar.

There is, however, a certain relation between gum and sugar of milk, since both of them, when treated with nitric acid, yield the same oxidized product, namely, mucic acid, which cannot under the same circumstances, be formed from any of the other kinds of sugar.

both yield mucic acid.

Composition of these substances. In order to show more distinctly the similarity of composition in these different substances, which perform so important a part in the nutritive process of the graminivora, let us represent one equivalent of carbon by C (= 75·8), and one equivalent of water by *aqua* (=112·4), we shall then have for the composition of these substances the following expressions:—

Starch	=	12 C + 10 aqua.
Cane Sugar	=	12 C + 10 aqua + 1 aqua.
Gum	=	12 C + 10 aqua + 1 aqua.
Sugar of milk	=	12 C + 10 aqua + 2 aqua.
Grape Sugar	=	12 C + 10 aqua + 4 aqua.

For the same number of equivalents of carbon, starch contains 10 equivalents, cane sugar and gum 11 equivalents, sugar of milk 12 equivalents, and grape sugar 14 equivalents, of water, or the elements of water.

Organic acids. Besides these substances, which contain carbon and the elements of water, the herbivorous animal receives in its food other organic compounds, namely, certain quantities of organic acids, of tartaric acid, citric acid (in potatoes and turnips), oxalic acid (in roots, barks, and leaves), and other acids; as also

substances like wax, in the leaves, and fats both liquid and solid, chiefly in seeds.

XV.

The non-nitrogenized constituents of food serve for respiration.

In these different substances some one of which is never wanting in the food of the graminivora, there is added to the sulphurized and nitrogenized constituents of this food, to the vegetable albumen, fibrine and caseine from which their blood is formed, strictly speaking, only a certain excess of carbon, which the animal organism cannot possibly employ to produce fibrine or albumen, because the nitrogenized constituents of the food already contain the carbon necessary for the production of blood, and because the blood in the body of the carnivora is formed without the aid of this excess of carbon.

The function performed in the vital process of the graminivora by these substances (sugar, gum, &c.) is indicated in a very clear and convincing manner when we take into consideration the very small relative amount of the carbon which these animals consume in the nitrogenized constituents of their food; for this bears no proportion whatever to the oxygen absorbed through the skin and lungs.

A pig, eight months old, fed exclusively with potatoes, and weighing 120 lbs., consumes daily in 14lbs. of potatoes $\frac{7}{10}$ths oz. of nitrogen.

If we calculate this nitrogen in the form of vegetable albumen, the animal receives, in that form, only $3\frac{1}{4}$ oz. of carbon.

In the form of wax-like matters soluble in ether, which we shall call fat, the animal received only $\frac{4}{10}$ oz. of carbon; but in the same time it expires, in the form of carbonic acid, 21 oz. of carbon. (Boussingault. See Appendix.)

A horse, for example, can be kept in perfectly good condition, if he obtain as food 15 lbs. of hay and $4\frac{1}{2}$ lbs. of oats daily. If we now calculate the whole amount of nitrogen in these matters, as ascertained by analysis (1·5 per cent. in the hay, 2·2 per cent. in the oats), (10) in the form of blood, that is, as fibrine and albumen, with the due proportion of water in blood (80 per cent.), the horse

receives daily no more than $4\frac{1}{2}$ oz. of nitrogen, corresponding to about 8 lbs. of blood. But along with this nitrogen, that is, combined with it in the form of fibrine or albumen, the animal receives only $14\frac{1}{2}$ oz. of carbon, and in the form of matter soluble in ether, 5 oz. more of carbon, in all, therefore, $19\frac{1}{2}$ oz. Only about 13 oz. of this can be employed to support respiration, for with the nitrogen expelled in the urine there are combined, in the form of urea, 3 oz., and in the form of hippuric acid, $3\frac{1}{2}$ oz., of carbon.

Without going further into the calculation, it will readily be admitted that the volume of air inspired and expired by a horse, the quantity of oxygen consumed, and, as a necessary consequence, the amount of carbonic acid given out by the animal, are much greater than in the respiratory process in man. But an adult man consumes daily about 14 oz. of carbon, and the determination of Boussingault, according to which a horse expires 79 oz. daily, cannot be very far from the truth.

In the nitrogenized constituents of their food, therefore, the horse receives only somewhat more than the fifth part, the pig only the sixth part, of the carbon, which their organism requires for the support of the respiratory process; and we see that the wisdom of the Creator has added to all the substances, without exception, which serve for their food, the carbon which is wanted in the nitrogenized constitutents, in various forms, such as starch, sugar, &c., which are indispensable to the animal for the keeping up of its temperature, and for the conversion into oxidized compounds of the inspired oxygen. If these substances had not been supplied in the food, then the body of the animal itself, with an equal consumption of oxygen, must have yielded the elements required for the above-named purposes.

It appears from these considerations, that the fat, which in the body of the carnivorous animal serves to maintain the vital process, as well as that of respiration, is replaced, in the food of the herbivorous animal, by substances, which perform the same function. These substances are, like fat, destitute of nitrogen; they contain also *carbon*, and the elements of *water*, while fat may be viewed as composed of *carburetted hydrogen*, *plus* a certain quantity of *water*.

XVI.

Relation between the food and the formation of fat.

If we now compare the capacity for increase of mass, the assimilative power, in the graminivora and carnivora, the commonest observations indicate a very marked difference.

A spider which sucks with extreme voracity the blood of the first fly, is not disturbed or excited by a second or a third. A cat will eat the first, and perhaps the second mouse presented to her, but even if she kills a third, she does not devour it. Exactly similar observations have been made in regard to lions and tigers, which only devour their prey when urged by hunger.

How different is the energy and intensity of vegetative life in the graminivora. A cow, or a sheep, in the meadow, eats, almost without interruption, as long as the sun is above the horizon. Their system possesses the power of converting into organized tissues all the food they devour beyond the quantity required for merely supplying the waste of their bodies.

All the excess of blood produced is converted into cellular and muscular tissue; the graminivorous animal with increased food, becomes fleshy and plump, while the flesh of the carnivorous animal is always tough and sinewy.

If we consider the case of a stag, a roe-deer, or a hare, animals which consume the same food as cattle and sheep, it is evident that, when well supplied with food, their growth in size, their fattening, must depend on the quantity of vegetable albumen, fibrine, or caseine which they consume. With free and unimpeded motion and exercise, enough of oxygen is absorbed to consume the carbon of the gum, sugar, starch, and of all similar soluble constituents of their food.

The fat of herbivora proceeds from starch, sugar, &c.

But all this is very differently arranged in our domestic animals, when, with an abundant supply of food, we check the processes of cooling and exhalation, as we do when we feed them in stables, where free motion is impossible.

The stall-fed animal eats, and reposes merely for digestion. It devours in the shape of nitrogenized compounds far more food

than is required for reproduction, or the supply of waste alone; and at the same time it eats far more of substances devoid of nitrogen than is necessary merely to support respiration and to keep up animal heat. Want of exercise and diminished cooling are equivalent to a deficient supply of oxygen; for when these circumstances occur, the animal absorbs much less oxygen than is required to convert into carbonic acid the carbon of the substances destined for respiration. Only a small part of the excess of carbon thus occasioned is expelled from the body in the horse and ox, in the form of hippuric acid; and all the remainder is employed in the production of a substance which, in the normal state, only occurs in small quantity as a constituent of the nerves and brain. This substance is *fat.*

Influence of exercise and temperature on the formation of fat.

In the normal condition, as to exercise and labor, the urine of the horse and ox contains benzoic acid (with 14 equivalents of carbon); but as soon as the animal is kept quiet in the stable, the urine contains hippuric acid (with 18 equivalents of carbon).

In the flesh of wild animals, as of the deer, the roe, or the hare, no fat is visible to the eye; but domestic animals, when fed, become covered with fat. It is only at certain times of years, that the flesh of wild animals is fat.

When the fattened animal is allowed to move more freely in the air, or compelled to draw heavy burdens, the fat again disappears.

It is evident, therefore, that the formation of fat in the animal body is the result of a want of due proportion between the food taken into the stomach and the oxygen absorbed by the lungs and the skin.

A pig, when fed with highly nitrogenized food, becomes full of flesh: the starch and sugar contained in its food increase the amount of fat in the body. The milk of a cow, when stall-fed, is very rich in butter, but in the meadow is found to contain more caseine, and in the same proportion less butter and sugar of milk. In the human female, beer, and farinaceous diet increase the proportion of butter in the milk; an animal diet yields less milk, but it is richer in caseine.

The amount of fatty matter in the food of fattened animals does not explain the accumulation of fat on their bodies.

If we consider, that the roots and herbs which a milch cow consumes, contain no butter; that no ox-tallow exists in the hay and other food of cattle, no hog's-lard in potatoes, and no goose or capon fat in the food of geese or poultry; also that accurate experiments prove that the fatty and wax-like matters of the food which are soluble in ether, are partly recovered in the excrements, and that even the whole would be far from sufficient to explain the increase of fat in the animal body in a given time:—

The carnivora produce (in their natural state) no fat.

If, moreover, we reflect, that in the entire class of carnivora, the food of which contains no substance devoid of nitrogen except fat, the production of fat in the body is utterly insignificant; that even in these animals, as in dogs and cats, it increases as soon as they live on a mixed diet; and that we can increase the formation of fat in other domestic animals at pleasure, but only by means of food containing no nitrogen; we can hardly entertain a doubt that such food, in its various forms of starch, sugar, &c., is closely connected with the production of fat.

In the natural course of scientific research, we draw conclusions from the food in regard to the tissues or substances formed from it; from the nitrogenized constituents of plants we draw certain inferences as to the nitrogenized constituents of the blood; and it is quite in accordance with this, the natural method, that we should seek to establish the relations of those parts of our food which are devoid of nitrogen and those parts of the body which contain none of that element. The most recent observations have pointed out the influence of the non-nitrogenized matters above mentioned on the formation of fat, and have established beyond a doubt, that starch and analogous substances in the animal body, at least in the normal condition of health and nutrition, are converted into fat.

XVII.

The alcohol of the fermented liquors consumed

Besides fat and those substances which contain carbon and the elements of water, man consumes, in the shape of the alcohol of fermented liquors, another sub-

stance which, in his body, plays exactly the same part as the non-nitrogenized constituents of food.

disappears in the organism.

The alcohol, taken in the form of wine or any other similar beverage, disappears in the body of man.

Its great attraction for oxygen.

Although the elements of alcohol do not possess by themselves the property of combining with oxygen at the temperature of the body, and forming carbonic acid and water, yet alcohol acquires, by contact with bodies in the condition of eremacausis or absorption of oxygen, such as are invariably present in the body, this property in a far higher degree than is known to occur in the case of fat and other non-nitrogenized substances.*

It cannot be detected in the urine,

Decisive experiments have proved, that the Urine, after moderate use of wine, contains no appreciable trace of alcohol: it has even been found that the condensible fluid obtained by passing the expired air through a cooling apparatus, that is, the perspiration of the lungs, is, in the same circumstances, entirely free from alcohol. From these facts we can draw no other conclusion but this, that the elements of the alcohol consumed have been given out as oxidized products, the carbon as carbonic acid, the hydrogen as water. If, moreover, we reflect, that after the use of wine, the proportion of carbonic acid diminishes in a certain proportion, obviously corresponding to the hydrogen of the alcohol (*see* Vierordt), no doubt can remain that the elements of alcohol are available for the respiratory process, and are actually employed in respiration.

nor among the products of respiration.

It is plain that the quantity of alcohol, which can be given out in the form of an oxidized compound in a given time, depends on the quantity of oxygen taken up, or capable of being absorbed in the same time. If the amount of carbon taken up in the form of alcohol be greater than the amount of oxygen contained in the body, and necessary for its conversion into carbonic acid and water,

* When cod-liver oil is administered to persons accustomed to drink daily a certain quantity of wine, it often happens, that the inclination for wine is diminished, so that at last they can take no wine at all; obviously, because alcohol and fat oil in this case mutually impede the excretion of each other through the skin and lungs, since the body does not assimilate the fat. This may also possibly be the reason why most people find that they can take wine with animal food, but not with farinaceous or amylaceous food.

then the excess of alcohol must pass off as such, or in the form of a lower stage of oxidation, such as acetic or butyric acid; or else it must be discoverable in the body.*

It is given off when the supply of oxygen is deficient.

XVIII.

All those constituents of vegetables which contain oxygen, but are destitute of nitrogen, contain carbon and the elements of water. Without exception, they contain less oxygen than is necessary to convert their carbon and hydrogen into carbonic acid and water.

The non-nitrogenized constituents of plants.

Oxalic acid is the only vegetable product which, if supposed anhydrous, ($C_2\ O_3$), contains no hydrogen.

In many volatile oils, in caoutchouc, &c., no oxygen is present.

If, now, it be beyond a doubt, that all the carbon of plants is derived from the Carbonic Acid of the atmosphere, and all their Hydrogen from Water, then the constituents of plants can have been formed in no other way than by the separation of Oxygen from Carbonic acid, and the replacement of a part or of the whole of its Oxygen by its equivalent of Hydrogen.

Their carbon is derived from carbonic acid, their hydrogen from water.

A constituent of plants, which contains four, six, or twelve equivalents of Carbon, has obtained these 4, 6, or 12 eq. of Carbon, from 4, 6, or 12 eq. of Carbonic Acid. If this constituent of plants contain 4, 6, or 12 eq. of Hydrogen, these have been derived from 4, 6, or 12 eq. of Water.

If we imagine the constitution of Carbonic Acid to be analogous to that of the organic acids, then it consists of oxygen, united to a compound radical, namely, Carbonic

Constitution of carbonic acid.

* In England, servants receive daily a certain amount of beer, or, in the case of total abstinence, its equivalent in money. A friend informs me that in a certain household it was observed, that, from the day on which the servants ceased to receive beer from their master, the consumption of bread increased in a ratio, corresponding to the diminution of beer; so that the beer was twice paid for, once in money, and the second time in the form of an equivalent of another kind of food, yielding the same amount of carbon and hydrogen.

Oxide. The whole chemical relations of Carbonic Oxide are in harmony with this view.

The composition of Carbonic Acid, on the view just stated, will be expressed by the following formula:

$$C\,O_2 = C\,O + O.$$

Its radical.

If we consider C O to be one equivalent of the Radical, and call it R (= C O), then we have

$$\text{Carbonic Acid } C\,O + O = R + O.$$

If we now suppose, that in the organism of the plant, the Carbonic acid has been decomposed, and $\frac{1}{8}$, $\frac{1}{7}$, $\frac{1}{6}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, or $\frac{1}{2}$ of its oxygen separated, this may be represented in a formula, in which the radical has been increased in a corresponding ratio. If, for example, Carbonic Acid, in order to be converted into Oxalic Acid, loses $\frac{1}{4}$ of its oxygen, this can be expressed by the formula:

Conversion of carbonic acid into oxalic acid.

$$\text{Oxalic Acid} = C_2\,O_3$$
$$\text{or by } C_2\,O_2 + O = 2\,R + O.$$

If we now suppose, further, that the Oxygen of the Carbonic Acid has been separated and replaced by its equivalent of Hydrogen, we obtain, in this way, compounds of different properties, according as it is the oxygen of the radical C O, or that which we imagine to be external to the Radical and combined with it, which is replaced by Hydrogen.

Let us, for example, suppose the oxygen in the Radical to be replaced by Hydrogen. Then, we have

1. $C\,O + O = R + O$ = Carbonic Acid.
2. $C\,H + O = R + O$

both compounds of analogous constitution, and only differing in this, that the Radical (C H) of the second compound is a carburetted Hydrogen, corresponding to Carbonic Oxide.

If we now suppose that in the Carbonic Acid, it is the oxygen external to the Radical which is replaced by Hydrogen, then the properties of this compound, must of necessity be different from those of the former. If the first were an acid, the second might be a neutral body.

$$C O + O = R + O = \text{Carbonic Acid.}$$
$$C O + H = R + H$$

If we again suppose that all the Oxygen, both in the radical, and external to it, is replaced by Hydrogen, then we have a Carburetted Hydrogen, corresponding to carbonic acid, such, indeed, as actually occurs in the form of marsh gas.

$$C O + O = R + O = \text{Carbonic Acid.}$$
$$C H + H = R + H \text{ Marsh Gas.}$$

Conversion of carbonic acid into other organic acids.

All such organic compounds as contain Carbon, and the elements of Water, belong, when viewed as derived from Carbonic Acid, to one or other of the following series:

$R + O;\ 2R + 2O;\ 3R + 3O;\ 4R + 4O$, &c. — Carbonic Acid.
$2R + O;$
$3R + O;\ \ 3R + 2O;$
$4R + O;\ \ 4R + 2O;\ \ 4R + 3O;$
$5R + O;\ \ 5R + 2O;\ \ 5R + 3O;\ \ 5R + 4O$, &c.
$6R + O;\ \ 6R + 2O;\ \ 6R + 3O;\ \ 6R + 4O$, &c.
$7R + O;\ \ 7R + 2O;\ \ 7R + 3O;\ \ 7R + 4O$, &c.
$8R + O;\ \ 8R + 2O;\ \ 8R + 3O;\ \ 8R + 4O$, &c.
⋮ ⋮ ⋮ ⋮
$34R + O;\ 34R + 2O;\ 34R + 3O;\ 34R + 4O$, &c.

Altogether independently of the ideas which we may form to ourselves, concerning the power of the organic acids to neutralize bases, and form salts with them, we have reason to think that all these bodies have an analogous constitution; and it is probably the most natural supposition, that they contain, in each case, a compound Radical, of which Hydrogen is an element; in such a manner, therefore, that the conversion of Carbonic Acid into an organic Acid, has been effected by the replacement of a part, or of the whole of the Oxygen of the Radical by Hydrogen.

In this way, for example, the Formic Acid may be viewed as the first member of the second series above given; or it may be viewed as Carbonic Acid, in the radical of which half the Oxygen has been replaced by Hydrogen.

Their relation to carbonic acid.

Not less simple, in this point of view, is the constitution and derivation of the most common and abundant organic Acids, of Tartaric Acid, Citric Acid, Malic Acid, and Acetic Acid.

Carbonic Acid;	$C_2 \left.\begin{matrix}O\\O\end{matrix}\right\} + O_2 = 2\,R + 2\,O$
Formic Acid;	$C_2 \left.\begin{matrix}H\\O\end{matrix}\right\} + O_2 = 2\,R + 2\,O$
Oxalic Acid;	$C_2 \left.\begin{matrix}O\\O\end{matrix}\right\} + O \;= 2\,R + O$
Malic Acid;	$C_4 \left.\begin{matrix}H_2\\O_2\end{matrix}\right\} + O_2 = 4\,R + 2\,O$
Acetic Acid;	$C_4 \left.\begin{matrix}H_3\\O\end{matrix}\right\} + O_2 = 4\,R + 2\,O$
Tartaric Acid;	$C_4 \left.\begin{matrix}H_2\\O_2\end{matrix}\right\} + O_3 = 4\,R + 3\,O$*
Citric Acid;	$C_{12} \left.\begin{matrix}H_5\\O_7\end{matrix}\right\} + O_4 = 12\,R + 4\,O.$

It is easy to see that the formulæ of Acetic and Malic Acids correspond to that of Oxalic Acid (only being doubled); and that Tartaric Acid is Carbonic Acid, in which half the oxygen of the Radical has been replaced by Hydrogen, while one-fourth of the Oxygen external to the radical has been separated or expelled without replacement.

Conversion of malic acid into Fumaric and maleic acids.

Malic Acid, when acted on by heat, yields Fumaric Acid and Maleic Acid; Citric Acid, in the same circumstances, yields Aconitic Acid; thus is obtained a new series of acids, which are also found generally diffused in vegetables.

These changes are quite simply effected by the separation of water, or by the separation of Hydrogen and Oxygen from the elements of the Radical of the acid.

* *Note by the Editor.*—As Tartaric acid is now admitted to be bibasic, and to have the formula (anhydrous) $C_8\,H_4\,O_{10}$, it would appear that the formula in the text is, strictly speaking, that of the isomeric acid, Racemic acid, which occurs along with Tartaric acid in the juice of some grapes, and is considered monobasic. The tartaric acid would then be thus represented on the above principle.

$$\text{Tartaric Acid; } C_8 \left.\begin{matrix}H_4\\O_4\end{matrix}\right\} + O_6 = 8\,R + 6\,O.$$

W. G.

Malic Acid	becomes	Maleic Acid.*
$C_4\left.\begin{matrix}H_2\\O_2\end{matrix}\right\} + 2O$		$C_4\left.\begin{matrix}H\\O\end{matrix}\right\} + 2O$
Citric Acid	becomes	Aconitic Acid.
$C_{12}\left.\begin{matrix}H_5\\O_7\end{matrix}\right\} + 4O$		$C_{12}\left.\begin{matrix}H_3\\O_5\end{matrix}\right\} + 4O$

Thus also, by the action of heat on Acetic Acid, the elements of 1 eq. Carbonic Acid are separated from those of the acetic acid, and we obtain a neutral combustible liquid, Acetone.

Acetic Acid	becomes	Carbonic Acid.
$C_4\left.\begin{matrix}H_3\\O\end{matrix}\right\} + 2O$		$CO + O$
		and Acetone
		$C_3\left.\begin{matrix}H_3\\O\end{matrix}\right\}$

In this way, and also because the replacement of the Oxygen in Carbonic Acid by Hydrogen does not take place, at all times, equivalent for equivalent, but in unequal proportions, as when, for example, the whole Oxygen within and without the supposed Radical being separated, one equivalent of that oxygen is expelled without any replacement by Hydrogen; or when, for 2, 3, or 4 eq. of Oxygen separated, only one equivalent of Hydrogen enters into the compound, there arise new series of compounds in different stages, the Radical of which differs from Carbonic Oxide, the Radical of Carbonic Acid. Thus Benzoic Acid, and Oil of Bitter Almonds, (Hyduret of Benzoyle,) belong to none of the series mentioned above; they contain a new Radical, which has been derived from the Radical of Carbonic Acid by the expulsion, *without replacement*, of half its Oxygen, and by the replacement of part of the other half by 5 eq. Hydrogen. Thus we have

Carbonic Acid........	$C_{14}\left.\begin{matrix}O_7\\O_7\end{matrix}\right\} + O_{14}$
Benzoic Acid.........	$C_{14}\left.\begin{matrix}H_5\\O_2\end{matrix}\right\} + O$
Oil of Bitter Almonds..	$C_{14}\left.\begin{matrix}H_5\\O_2\end{matrix}\right\} + H$

(In these formulæ we see that in Carbonic Acid, viewed in

* The composition of Fumaric Acid is the same as that of Meleic Acid, although its properties are different.—W. G.

reference to 14 eq. of Carbon, (the smallest quantity which could give rise to Benzoic Acid), half the Oxygen must be considered external to the Radical, if that Radical be Carbonic Oxide, 14 C $O = C_{14}O_{14}$; that in Benzoic Acid, this radical has lost half its oxygen without replacement, and that of the remaining half or 7 eq. Oxygen, 5 eq. are replaced by hydrogen, yielding the new Radical Benzoyle, $C_{14}H_5O_2 = Bz$, which then takes up 1 eq. Oxygen external to the Radical, to form Benzoic Acid, and 1 eq. Hydrogen external to the Radical, to form the Oil of Bitter Almonds.—W. G.)

Conversion of organic acids into neutral bodies.

When we consider more closely the formulæ of Malic and Tartaric Acids, the most common and abundant organic acids, and when we bear in mind that they have been derived from Carbonic Acid by the separation of Oxygen and the assimilation of a certain amount of Hydrogen; if we further assume as certain, that these acids, in the organism of the plant, are capable of suffering further change by the action of the same causes which have effected the decomposition of Carbonic Acid, it follows necessarily that, by the simple separation of a new portion of Oxygen, these acids must gradually lose their distinctive character, and be converted into other, but neutral, compounds, which contain Hydrogen and Oxygen in the proportions necessary to form water, that is, in the same proportion as that in which these two elements exist in Sugar, Gum, Starch, and Woody fibre.

If, from the composition of Malic Acid, 2 eq., and from that of Tartaric (Racemic) Acid 3 eq. of Oxygen separate, we obtain

From Malic Acid, $C_4 \left.\begin{matrix} H_2 \\ O_2 \end{matrix}\right\} + 2\,O$, the body $C_4 \left.\begin{matrix} H_2 \\ O_2 \end{matrix}\right\}$; and

from Tartaric Acid, $C_4 \left.\begin{matrix} H_2 \\ O_2 \end{matrix}\right\} + 3\,O$, the body $C_4 \left.\begin{matrix} H_2 \\ O_2 \end{matrix}\right\}$.

(These bodies may be identical, or they may be *isomeric*, and of course various products will be formed according as 1, 2, 3 or more equivalents of $C_4 \left.\begin{matrix} H_2 \\ O_2 \end{matrix}\right\}$ constitute an equivalent of the new body, in which case the different compounds are *polymeric*.—W. G.)

Now, by the simple addition of 1 eq., $1\frac{1}{3}$ eq., $1\frac{2}{3}$ eq., or 2 eq. of Water to the body $C_4H_2O_2$, or, to avoid the use of fractions,

by the addition, to 3 eq. of $C_4H_2O_2$, $(=C_{12}H_6O_6)$ of 3 eq., 4 eq., 5 eq., and 6 eq. of water, we obtain the composition of Woody fibre, $C_{12}H_9O_9$; of Starch, $C_{12}H_{10}O_{10}$; of Gum, $C_{12}H_{11}O_{11}$; and of Grape Sugar, $C_{12}H_{12}O_{12}$.

Most of the above-mentioned organic acids contain, in their Radical, Hydrogen and Oxygen, and indeed, they either contain both in the proportion to form water, or more Oxygen than corresponds to that proportion.

Acetic Acid and all fatty and oily acids contain in this Radical an excess of Hydrogen beyond the proportion necessary to form water. From Acetic Acid upwards, in no one of them is the Oxygen sufficient to convert into water all the Hydrogen of the Radical.

Mutual relations of the fatty acids.

The most widely distributed fatty or oily acids may be considered, in the hydrated state, as compounds of Oxygen with the Radical of Carbonic Acid in which all the Oxygen has been replaced by Hydrogen. In the anhydrous state we should consider the Radical to retain, in each of them, 1 eq. of Oxygen not replaced. (Dumas.)

COMPOSITION OF THE MOST WIDELY DISTRIBUTED FATTY OR OILY ACIDS.

As hydrates, or in the separate State. R = C H.		As contained in their Salts, or in the Anhydrous state.
Butyric Acid	$8\,R + 4\,O$	$C_8 \left.\begin{matrix} H_7 \\ O \end{matrix}\right\} + 2\,O$
Valerianic Acid	$10\,R + 4\,O$	$C_{10} \left.\begin{matrix} H_9 \\ O \end{matrix}\right\} + 2\,O$
Caproic Acid	$12\,R + 4\,O$	$C_{12} \left.\begin{matrix} H_{11} \\ O \end{matrix}\right\} + 2\,O$
Capric Acid	$16\,R + 4\,O$	$C_{16} \left.\begin{matrix} H_{15} \\ O \end{matrix}\right\} + 2\,O$
Lauric Acid, Pichuric Acid	$24\,R + 4\,O$	$C_{24} \left.\begin{matrix} H_{23} \\ O \end{matrix}\right\} + 2\,O$
Cocinic Acid	$26\,R + 4\,O$	$C_{26} \left.\begin{matrix} H_{25} \\ O \end{matrix}\right\} + 2\,O$
Ethalic Acid, Palmatic Acid	$32\,R + 4\,O$	$C_{32} \left.\begin{matrix} H_{31} \\ O \end{matrix}\right\} + 2\,O$
Margaric Acid	$34\,R + 4\,O$	$C_{34} \left.\begin{matrix} H_{33} \\ O \end{matrix}\right\} + 2\,O$
Stearic Acid (bibasic)	$2\,(34\,R) + 7\,O$	$2\left(C_{34} \left.\begin{matrix} H_{33} \\ O \end{matrix}\right\}\right) + 3\,O$

It is hardly necessary to point out that the object of this table

is not to establish the constitution of these acids; the intention of this work is only to render intelligible the views entertained as to the origin or derivation, the analogy in composition, and the mutual relations of these substances.

The simplest consideration shows, that an organic compound must be placed higher in the scale of organic compounds, in proportion as its composition differs more widely from the original Type, represented by carbonic acid.

Among the neutral products of the vegetable kingdom, dry Grape Sugar, in composition, stands the nearest to Carbonic Acid, although, to judge from its chemical relations, the mode of arrangement of its elements must be different.

Cane Sugar, Gum, Starch, and Woody fibre, viewed in this way, appear as organic compounds standing higher in the scale. Thus we have

	Grape Sugar	Cane Sugar and Gum	Starch
Carbonic Acid $C_{12}\left.\begin{matrix}O_{12}\\O_{12}\end{matrix}\right\}$;	$C_{12}\left.\begin{matrix}H_{12}\\O_{12}\end{matrix}\right\}$;	$C_{12}\left.\begin{matrix}H_{11}\\O_{11}\end{matrix}\right\}$;	$C_{12}\left.\begin{matrix}H_{10}\\O_{10}\end{matrix}\right\}$.

If, therefore, it be assumed, that Starch, during digestion, is converted into Grape Sugar, then the conversion of Grape Sugar into Carbonic Acid is easily conceived, since it depends on a simple replacement of its Hydrogen by Oxygen.

Fermentation of sugar.

In the peculiar process which is called Fermentation, there is separated from the elements of Grape Sugar a certain quantity of Carbonic Acid; it is, therefore, obvious, that the only other product of the Fermentation, namely Alcohol, must also be a representative of Carbonic Acid. In fact, alcohol contains the same number of atoms as Carbonic Acid.

Carbonic Acid	Alcohol
$C_8\left.\begin{matrix}O_8\\O_8\end{matrix}\right\}$;	$C_8\left.\begin{matrix}H_{12}\\O_4\end{matrix}\right\}$.

In vegetables, sugar has thus been formed from Carbonic Acid, by the separation of Oxygen, and by the introduction of Hydrogen in the place of that Oxygen. In the animal organism, the process is reversed: the hydrogen, in the animal body, is removed and replaced by oxygen; and in this way the Carbon again assumes its original form of combination.

This is, generally speaking, the essential character of the process of eremacausis or respiration: it is an indirect process of combustion, going on at a low temperature, and with a limited supply of Oxygen. We are not acquainted with any case in which, under these circumstances, the Carbon of an organic substance combines directly with Oxygen to produce Carbonic Acid; no combustion of the Carbon, in the proper sense of the word, takes place, but the hydrogen of the compound is oxidized and separated as water, while its equivalent of Oxygen is taken up in its place. Should one of the intermediate compounds, which are formed by the gradual replacement of the Hydrogen by Oxygen, possess, in itself, an attraction for Oxygen, then for 1 eq. Hydrogen more than 1 eq. Oxygen is taken up.

Respiration is an indirect process of combustion;

the carbon is not burned.

The development of heat in the respiratory process, therefore, depends not on the direct oxidation of the Carbon, but on the conversion of the Hydrogen of the organic compound into water, and on the substitution of one or more equivalents of Oxygen for this Hydrogen.

The conversion of Alcohol into Carbonic acid, one of the processes of eremacausis (slow combustion), or decay which has been most carefully studied, may serve, perhaps, to render more easily comprehensible the changes which occur during the gradual replacement of Hydrogen by Oxygen.

Alcohol	Acetic Acid	Formic Acid	Carbonic Acid
$C_8 \left.\begin{matrix} H_{12} \\ O_4 \end{matrix}\right\}$;	$C_8 \left.\begin{matrix} H_8 \\ O_8 \end{matrix}\right\}$;	$C_8 \left.\begin{matrix} H_4 \\ O_{12} \end{matrix}\right\}$;	$C_8 \left.\begin{matrix} O_4 \\ O_{12} \end{matrix}\right\}$.

During the conversion of Alcohol into Acetic Acid, if less Oxygen be present than is necessary to replace the Hydrogen by its equivalent of Oxygen, 4 eq. Hydrogen are separated, without replacement, and there is produced the intermediate compound, Aldehyde, which, by direct absorption of Oxygen, is converted into Acetic Acid.

Alcohol	Aldehyde		Acetic Acid
$C_8 \left.\begin{matrix} H_{12} \\ O_4 \end{matrix}\right\}$;	$C_8 \left.\begin{matrix} H_8 \\ O_4 \end{matrix}\right\} + O_4$	$=$	$C_8 \left.\begin{matrix} H_8 \\ O_8 \end{matrix}\right\}$.

But Aldehyde, if Oxygen be supplied in sufficient quantity,

passes directly into Formic Acid; and in this case, for 4 eq. Hydrogen, which are oxidized, there are taken up not 4 but 8 eq. Oxygen.

$$\text{Aldehyde} + 12 \text{ eq. Oxygen} = \text{Formic Acid} + 4 \text{ eq. Water}$$
$$C_8 \left.\begin{matrix} H_8 \\ O_4 \end{matrix}\right\} + 12\,O = C_8 \left.\begin{matrix} H_4 \\ O_{12} \end{matrix}\right\} + 4\,H\,O$$

Here, of the 12 eq. Oxygen absorbed, 4 eq. combine with 4 eq. Hydrogen to form Water, and the remaining 8 eq. Oxygen combine with the residue of the Aldehyde, converting it into Formic Acid.

This is, however, not the only form of the process of eremacausis in the body; there is another, which is far more remarkable, and this second form must be especially considered in reference to the production of Fat from Sugar, or the conversion of Sugar into Fat.

Glycerine in fats.

The fatty bodies (fixed oils and fats), occurring in plants and animals, are considered as a peculiar kind of Salts, which consist of *Oxide of Glyceryle* and of acids which are either liquid or solid at ordinary temperatures. These salts possess a common property, that of being decomposed (saponified) by most metallic oxides; and in this decomposition the metallic oxide takes the place of the organic oxide. If, now, the metallic oxide be removed by an acid, we obtain the so-called hydrated fatty or oily acids, in which the metallic oxide is replaced by its equivalent of water.

Characters of fatty bodies.

A common character of all such fatty bodies as contain Oxide of Glyceryle is this; that when heated to decomposition, as in the destructive distillation, they yield a product, *Acroleine*, which has a most penetrating odor, attacks the eyes most violently, and which is derived from Oxide of Glyceryle. As the common character of all liquid fats or fixed oils we must regard, in addition to the production of Acroleine, the formation of a substance which is soluble in water and chrystallizable, and in many properties similar to Benzoic Acid, although differing from it in composition, namely, Sebacic Acid, $C_{10}H_9O_4$. Moreover, the Oleic Acid, which is liquid at ordinary temperatures, is converted, by contact with Nitrous or Hyponitric Acid, into a

solid chrystallizable acid, Elaidic Acid. This property is found in all the oils which consist chiefly of Oleic Acid.

The composition of Oleic Acid is represented by the formula $C_{36}H_{31}O$. (Gottlieb.) This differs essentially from the formulæ of the other fatty acids; for while these last, in the uncombined or hydrated state, contain an equal number of equivalents of Carbon and Hydrogen, indeed, in some cases, an excess of Hydrogen, Oleic Acid contains, for 36 eq. Carbon, only 34 eq. Hydrogen. When exposed to the air, it rapidly absorbs Oxygen and passes into the acid $C_{36}H_{33}O^5$. Elaidic Acid has the same composition as Oleic Acid. It is well worthy of remark, that, by the action of heat on Oleic Acid, there are formed, among other products, Capric and Caprylic Acids.

Wax is produced from sugar.

If it must be received as an undeniable truth, that wax is formed in the body of the bee out of Sugar, and that Fat in the body of the herbivorous animal is formed from starch, or (since starch can only be assimilated in the form of sugar), from sugar in the process of fattening, it is perfectly certain, that the conversion of Sugar into Fat only takes place in consequence of the simultaneous occurrence of the two processes of Fermentation and Decay or Eremacausis. In other words, the conversion of a substance rich in Oxygen, into another containing less Oxygen is determined by the splitting up, as it were, of the Sugar, into two compounds, one of which contains the oxygen which the other has lost, and, consequently, contains an excess of that element, when compared with the Sugar.

As has been explained in the preceding pages, the Oxygen in the processes of decay, combines with the Hydrogen of the substance, and the highly oxidized compounds given out in processes of Fermentation, are Carbonic Acid and Water.

According to this view, the conversion of Sugar into Fat is effected by the oxidation of its Hydrogen, and by the separation of a certain proportion of its Oxygen in the forms of Carbonic Acid and Water.

Production from sugar of butyric acid.

When a solution of Sugar is left to ferment, at a high temperature, in contact with putrefying Caseine, there is separated from the elements of the Sugar, if the oxygen of the air be excluded, a certain quantity of Carbonic

acid and of Hydrogen gases, and we obtain, as is now well known, a fatty or oily acid, the *Butyric Acid.*

It is plain that when this same acid is formed in the organism of the cow, which yields Butyric Acid in its Butter, no Hydrogen can be separated from the sugar *as such*, or uncombined, because, in this process, Oxygen is not excluded. The Hydrogen combines with the Oxygen which is carried to all parts of the body by the blood, and is then separated from the elements of the Sugar in the form of Water.

Of caproic acid, caprylic acid, and oxide of glyceryle.

The following formulæ, which are intended to illustrate the formation of some fatty acids from Sugar, show, at the first glance, that the diminution of the proportion of Oxygen in the fatty acid stands in a very definite relation to the amount of Oxygen given out in the forms of Carbonic Acid and Water.

$$\text{Sugar } C_{12}\left.\begin{matrix}H_{12}\\O_{12}\end{matrix}\right\} + 4O = \left\{\begin{array}{lll} C_8\,H_8\,O_4 & = & \text{Butyric Acid.}\\ \quad H_4\,O_4 & = & \text{Water.}\\ C_4 \quad O_8 & = & \text{Carbonic Acid.}\end{array}\right.$$

$$\text{Sugar } C_{18}\left.\begin{matrix}H_{18}\\O_{18}\end{matrix}\right\} + 4O = \left\{\begin{array}{lll} C_{12}H_{12}\,O_4 & = & \text{Caproic Acid.}\\ \quad H_6\,O_6 & = & \text{Water.}\\ C_6 \quad O_{12} & = & \text{Carbonic Acid.}\end{array}\right.$$

$$\text{Sugar } C_{24}\left.\begin{matrix}H_{24}\\O_{24}\end{matrix}\right\} + 4O = \left\{\begin{array}{lll} C_{16}H_{16}\,O_4 & = & \text{Caprylic Acid.}\\ \quad H_8\,O_8 & = & \text{Water.}\\ C_8 \quad O_{16} & = & \text{Carbonic Acid.}\end{array}\right.$$

$$\text{Sugar } C_{12}\left.\begin{matrix}H_{12}\\O_{12}\end{matrix}\right\} + 3O = \left\{\begin{array}{lll} C_9\,H_6\,O_3 & = & \text{Oxide of Glyceryle.}\\ \quad H_6\,O_6 & = & \text{Water.}\\ C_3 \quad O_6 & = & \text{Carbonic Acid.}\end{array}\right.$$

It would appear a mere playing with figures, if these examples were further extended; since we are not yet able to produce from sugar any fatty acid, with the exception of Butyric Acid. But we must not forget that Butyric Acid may actually be prepared from sugar, and that the fatty bodies, in general, are formed from sugar in the animal organism. The solid, crystallizable fatty acids, in reference to their constitution, belong to one type; and consequently, in their formation, like causes must have been in action in a like form.

Analogy between the formation of fat and the mouldering of wood.

The formation and production of fat from sugar cannot be imagined without a separation of oxygen in the form of carbonic acid, that is, without such a splitting up of the atom of sugar as occurs in the

processes of fermentation. It cannot be imagined, without a corresponding diminution of the amount of hydrogen, the excretion of which from the body, in the form of water, can only take place in consequence of the simultaneous occurrence of a process of eremacausis.

In these respects, the conversion of sugar into fat has the greatest analogy with the process of the decay of woody fibre ; and it is worthy of special attention here, that occasionally in decaying wood peculiar compounds are found, which have a great resemblance to fat.

XIX.

The value of the elements of respiration as sources of heat,

Those constituents of the food of man and of animals which, with the aid of the oxygen of the atmosphere, are given out from their bodies in the forms of carbonic acid and water, possess very unequal values in regard to the amount of heat which they can set free during their oxidation, or with reference to the time during which they can keep up the constant temperature of the body.

depends on the amount of unoxidized dydrogen they contain.

Of all bodies, hydrogen, during its combination with oxygen, gives out the greatest amount of heat; and if the conversion of a substance containing carbon and hydrogen into carbonic acid and water depends on the conversion into water of so much of its hydrogen as is not already in that form, and on the replacement of this hydrogen by one or more equivalents of oxygen, then it is evident that those substances have the highest value for respiration which are rich in combustible (that is, not oxidized) hydrogen, and which acquire most oxygen for the conversion into carbonic acid of the remaining carbon and oxygen.

Comparative values of different bodies.

If we attend, as the foundation of our calculation, to the amount of heat which is given out by the combination of oxygen with hydrogen and with carbon , and if we assume that the heat produced during the combustion (or oxidation) of different compounds is directly proportional to the amount of oxygen which they require for conversion into car-

bonic acid and water, then we obtain for cane sugar, sugar of milk (dry grape sugar), starch, fat, and flesh, the following results :—

Amount of oxygen required by elements of respiration for complete combustion.

1 pound of	Sugar of Milk	combines	with	187	volumes of	Oxygen Gas.
1 "	Cane Sugar	"	"	$196\frac{1}{2}$	"	"
1 "	Starch	"	"	207	"	"
1 "	Alcohol	"	"	$362\frac{3}{4}$	"	"
1 "	Fat	"	"	$511\frac{1}{4}$	"	"

Amount of heat thus developed.

These different bodies, in combining with oxygen, are able to raise, from 32° to 33·8 F. (from 0° to 1° cent.), the following comparative number of pounds of water :—

1 pound of	Sugar of Milk	raises from 32° to 33·8 the tempera-	ture of	4012	pounds of	Water.
1 "	Cane Sugar	"	"	4174	"	"
1 "	Starch	"	"	4353	"	"
1 "	Alcohol	"	"	7837	"	"
1 "	Fat	"	"	10491	"	"

Values according to the unequal times in which the combustion of equal weights takes place.

If we estimate at 50 lbs. the water present in the body of a man weighing 110 lbs., then equal weights of these different substances will suffice to keep the temperature of the body constant, *cæteris paribus,* during a certain number of hours, different for each substance. If, for example, 1 part by weight of Sugar of Milk can keep up the temperature of the body at the normal height for 33 hours, then an equal weight of Cane Sugar will keep it up for 35 hours, an equal weight of Starch for 36 hours, an equal weight of Alcohol for 65, and an equal weight of Fat for 87 hours.

Values according to their weight, the consumption of oxygen being equal.

The weights in the following tables express the quantities of some substances which, the consumption of Oxygen being equal, are employed in respiration :

100 Litres of Oxygen Gas combine with		and raise from 32° to 98·6° F. the temperature of		
133·7 grammes	Sugar of Milk	 28,996	pounds of	Water.
127·2 "	Cane Sugar	 28,704	"	"
120·2 "	Starch	 28,356	"	"
68·9 "	Alcohol	 29,188	"	"
48·8 "	Fat	 27,674	"	"

Value of flesh as an element of respiration.

If we suppose that the flesh, (free from fat), consumed by a carnivorous animal, is converted in the body, into Urea, Carbonic Acid and Water, and if we assume, that the flesh contains, in 100 parts, 74 of water and 26 of dry matter, then 1 pound of recent flesh requires for this change 137·1 Litres of Oxygen Gas; or 100 Litres of Oxygen Gas combined with 364 grammes of flesh. By means of 1 lb. of flesh, therefore, 1382 lbs. of water may be warmed from 32° to 33·8° F. (0° to 1° C.).

Value, as sources of heat, of the elements of respiration, for equal times.

In order to keep the body at the same temperature during equal times, there are required, of—

Cane Sugar........	100	parts
Grape Sugar	106	"
Starch	97·2	"
Alcohol	53·8	"
Fat	40·2	"
Flesh	309.7	"

Pure flesh, therefore, possesses the smallest, and Fat the greatest value as an Element of Respiration.*

XX.

Food of carnivora; fat contained in it.

The quantity of non-nitrogenized substances which herbivorous and carnivorous animals consume in their food, and employ in the respiratory process, is very unequal.

Proportion of the non-nitrogenized constituents in the food of a pig and of a horse.

The amount of Carbon expired in 24 hours by a pig of 8 months old, fed on potatoes, is about 21 oz.; the amount expired by a horse is 79 oz.

In the former animal, the amount of carbon consumed in the form of the constituents of the blood

* If, in calculating the above values, we attend to the prevailing views in regard to the constitution of alcohol, sugar, &c., especially in reference to the existence of ready formed water in them, we shall have to make some alteration on the proportions above given. But for our present object this is of no importance; because we do not know the true value, as a source of heat, of any one of these substances, and the above numbers only furnish an approximation.

(calculated on the amount of nitrogen in the food), is to the total quantity of carbon expired, as 1 : 6 : in the latter, the horse, as 1 : 5. If, therefore, we assume that, in the most favorable case, the whole Carbon of the constituents of blood has been given out of the bodies of these animals in the form of Carbonic Acid, still the total quantity consumed in respiration must be at all events four or five times as great.

For every pound of Carbon in the form of the constituents of blood (fibrine, albumen, or caseine), there must have been consumed, in the pig, 5 lbs. in the form of starch; or for one part by weight of dry fibrine, &c., (calculated to contain 53 per cent. of Carbon), 6 parts by weight of starch.

Equivalent of starch expressed in fat.

As an element of respiration, 6 parts of starch, the consumption of Oxygen being equal, correspond to 2·4 parts of Fat.

Equivalent of vegetable albumen expressed in flesh.

One part, by weight, of dry vegetable albumen (a constituent of blood) corresponds, very nearly, to 4 parts of recent flesh.

Comparison of the food of an herbivorous animal with that of a carnivorous animal.

It is clear, therefore, that if the respiratory process in a carnivorous animal took place in exactly the same way as in the pig fed on potatoes, but not fattened, the carnivorous animal must consume, with every pound of fresh muscular flesh, 0·6 lb. or 9·5 oz. of Fat.

Amount of fat in flesh.

Now it has been found on investigation, that recent muscular flesh, cleaned from all adhering fat as far as is possible with the hand, contains, in the following animals, the quantities of Fat indicated in the following table:—

1 lb of muscular flesh, cleaned from all visible fat, contains:—

In the Ox fattened	Sheep fattened	Pig fattened	Calf	Hare
0·25 oz.	0·3 oz.	0·875 oz.	0·01 oz.	0·0135 oz.

1 lb. of muscular flesh, with all adhering fat,* yielded:

In the Ox fattened	Sheep fattened	Pig fattened	Calf	Hare
1·4 oz.	3·34 oz.	4·16 oz.	0·175 oz.	0·315 oz.†

* As obtained from the Butcher.

† In these determinations, the flesh was boiled with diluted hydrochloric

The amount of non-nitrogenized elements of respiration is far smaller in the food of the carnivora than in that of the herbivora.

When a carnivorous animal, therefore, is fed with muscular flesh (without adhering fat), the fat contained in the food amounts in the flesh of the Ox to $\frac{1}{38}$, of the Sheep to $\frac{1}{32}$, of the Pig to $\frac{1}{10}$, of the Calf only to $\frac{1}{950}$, and of the Hare only to $\frac{1}{704}$ of the total quantity of fat, which would be necessary, as an addition to the nitrogenized constituents of its food, in order to support the respiratory process in the same form as in the Pig.

If we assume that the carnivorous animal had consumed an entire ox, sheep, or pig (in the fattened condition), or a calf or hare, with all the adhering fat, then the non-nitrogenized matter (the Fat) contained in the food would have amounted in the Ox, to only 0·123, in the Sheep to 0·244, in the Pig to 0·303, in the Calf to 0·013, and in the Hare to 0·023; in the two last cases, therefore, only to from 2 to 3 per cent. of the non-nitrogenized matter which the Pig, fed on potatoes, with an equal amount of the constituents of blood, consumes in its food.

The respiratory process differs in form in the two classes of animals.

Carnivorous animals, whose food, on the average, cannot differ much from the flesh of the calf (unfattened) or of the hare, receive, therefore, in their food, a far smaller quantity of non-nitrogenized substances than herbivorous animals do; and it follows evidently, that in these two classes of animals, the respiratory process must be different, both in reference to its form, and to the time during which it takes place.

The carnivora respire at the expense of the constituents of their blood, or of the products of the change of matter.

The quantity of non-nitrogenized substances in the food of the carnivora, when compared with that in the food of the herbivora, does not suffice, with an equal consumption of Oxygen, to keep up the temperature of the body; it is plain that the Carbon and Hydrogen necessary for the conversion into Carbonic Acid and Water of the absorbed Oxygen, must be supplied from

acid, till the fibrine and tissues were entirely dissolved, and the fat had completely risen to the surface. The fat of hare flesh is of oily consistence, and could only be exactly determined by adding a known weight of wax, which, after consolidation, showed by its increase of weight the amount of Fat. All the fat, in these researches, was kept melted in the water bath, until it ceased to lose weight, before it was finally weighed.

the substances of the living tissues, or, what is ultimately the same thing, from the flesh consumed as food.

In the body of the herbivorous animal, on the supposition that the fibrine, albumen, &c. consumed, are entirely given off in the forms of Carbonic Acid, Water, and Urea, out of 100 volumes of oxygen, only 17 volumes combine with the elements of the fibrine, &c., and 83 volumes with the non-nitrogenized elements of its food. But in the body of the carnivorous animal, fed on veal, out of 100 volumes of oxygen only 7·7 volumes are employed in converting the Fat into Carbonic Acid and Water, while 92·3 volumes are consumed in the conversion into Carbonic Acid, Water and Urea of the flesh, or of the products of the transformation of the nitrogenized constituents of the tissues of the animal.

The change of matter must yield more elements of respiration in a given time than in the herbivora.

It is obvious that in the organism of the graminivora, whose food is far richer in non-nitrogenized substances containing much Carbon and Hydrogen, for an equal consumption of oxygen the process of metamorphosis of existing tissues, and consequently their restoration or reproduction, must go on far less rapidly than in the carnivora. Were this not the case, a vegetation a thousand times more luxuriant than the actual one would not suffice for their nourishment. Sugar, gum, and starch would no longer be necessary to support life in these animals, because, in that case, the products of the waste, or metamorphosis of the organized tissues, would contain enough of carbon to support the respiratory process.

Man, when confined to animal food, requires for his support and nourishment extensive sources of food, even more widely extended than the lion and tiger, because, when he has the opportunity, he kills without eating.

A nation of hunters, on a limited space, is utterly incapable of increasing its numbers beyond a certain point, which is soon attained. The carbon necessary for respiration must be obtained from the animals, of which only a limited number can live on the space supposed. These animals collect from plants the constituents of their organs and of their blood, and yield them, in turn, to the savages who live by the chase alone. They, again, receive

this food unaccompanied by those compounds, destitute of nitrogen, which, during the life of the animals, served to support the respiratory process. In such men, confined to an animal diet, it is the carbon of the flesh and of the blood which must take the place of starch and sugar.

With an equal consumption of oxygen, 3 lbs. of flesh as an element of respiration, correspond to 1 lb. of starch. While the savage with 1 lb. of flesh, and an equal weight of starch, could maintain life and health during a certain time, he would be compelled, if confined to flesh, in order to procure the elements necessary for respiration during the same time, to consume 4 lbs. of flesh.

It is easy to see, from these considerations, how close the connection is between agriculture and the multiplication of the human species. The cultivation of our crops has ultimately no other object than the production of a maximum of those substances which are adapted for assimilation and respiration, in the smallest possibly space. Grain and other nutritious vegetables yield us, not only in starch, sugar, and gum, the carbon which protects our organs from the action of oxygen, and produces in the organism the heat which is essential to life, but also in the form of vegetable fibrine, albumen, and caseine, our blood, from which the other parts of our body are developed.

Man, when confined to animal food, respires, like the carnivora, at the expense of the matters produced by the metamorphosis of organized tissues; and, just as the lion, tiger, and hyæna, in the cages of a menagerie, are compelled to accelerate the waste of organized tissues by incessant motion, in order to furnish the matter necessary for respiration, so, the savage, whose respiratory process is likewise kept up by the products of the metamorphosis of his tissues, is compelled to consume force merely in order to supply matter for respiration.

Cultivation is the economy of force. Science teaches us the simplest means of obtaining the greatest effect with the smallest expenditure of power, and with given means to use a maximum of force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or of the want of cultivation.

XXI.

The abnormal condition, which causes the deposit of fat in the animal body, depends, as was formerly stated, on a disproportion between the quantity of carbon and hydrogen in the food and that of oxygen absorbed by the skin and lungs.* In the normal condition, the quantity of carbon and hydrogen given out is exactly equal to that which is taken in the food, and the body acquires no increase of weight from the accumulation of substances containing much carbon and no nitrogen.

If we increase the supply of food rich in Carbon and Hydrogen, then the normal state can only be preserved on the condition that, by exercise and labor, the waste of the body is increased, and the supply of oxygen augmented in the same proportion.

The formation of fat is the result of a deficiency of oxygen.

The production of fat is always a consequence of a deficient supply of oxygen, for oxygen is absolutely indispensable for the dissipation of the excess of carbon and hydrogen in the food. This excess of carbon, deposited in the form of fat, is never seen in the Bedouin or in the Arab of the Desert, who exhibits with pride to the traveller his lean, muscular, sinewy limbs, altogether free from fat; but in prisons and jails, it appears as a puffiness in the inmates, fed, as they are, on a poor and scanty diet; it appears in the sedentary females of Oriental countries; and finally, it is produced under the well-known conditions of the fattening of domestic animals.†

* In individuals possessing an abnormal tendency to fatness, the circulation is out of proportion with the digestion; and such persons have, in general, proportionately small lungs. A narrow chest (small lungs) is considered by experienced agriculturists as a sure sign, in pigs for example, of easy fattening; and the same remark applies to cows in reference to the produce of milk, that is, of butter.

† In applying these considerations to the nutrition and fattening of domestic animals, we must attend to the relative proportion of the bulk of the food to the amount of carbon contained in it. Thus, for example, 100 lbs. of potatoes contain only 12 lbs., 100 lbs. of mangel wurzel only 5 lbs., while 100 lbs. of pease contain 37 lbs. of carbon. For the purpose of fattening, 1 lb. of pease corresponds to 3 lbs. of potatoes, and to nearly 7 lbs. of turnips.

A pig 8 months old, weighing 120 lbs., consuming daily not more than 14 lbs of potatoes, obtains in this food, not more carbonized substances than it

The formation of fat depends on a deficiency of oxygen; but in this process, in the formation of fat itself, there is opened up a new source of oxygen, a new cause of animal heat. Is a source of animal heat.

The most general expression for the conversion of Sugar and Starch into Fat, is a separation and giving out of their Oxygen in the form of Carbonic Acid; and this separation of Carbonic Acid takes place in consequence of an absorption of Oxygen from the atmosphere, which combines with a part of the Hydrogen of the Sugar of Starch to form Water.

It is obvious, that by the formation of this water, heat must be developed; but the conversion of the Carbon of the Sugar into Carbonic Acid, for which the elements of the sugar have furnished the Oxygen, must produce a second quantity of heat, which is either equal to, or less than that which the same Oxygen would yield if directly converted into the same quantity of Carbonic Acid. During the conversion of Sugar, for example, into the least complex fatty acid, Butyric Acid, 4 eq. of oxygen from without combine with 4 eq. hydrogen in the Sugar to form water, and 8 eq. oxygen are separated from its elements in the form of Carbonic Acid. In the formation of this fatty acid, both water and carbonic acid are formed, the former by a process of eremacausis or decay, the latter by a process of fermentation; and both these processess are always accompanied by the disengagement of heat.

By the formation of Water, as well as by the production of Carbonic Acid, heat is developed, but the oxygen of the atmosphere only contributes to the former, and the disengagement of heat

requires for its normal nutrition, and for keeping up its respiratory process. The increase of fat and flesh is consequently trifling, and corresponds to the fact of its nearly complete development. As soon as it is fully grown, its weight, with the above supply of food, no longer increases, obviously because the bulk of the food does not allow it to take into its body a larger quantity. Consequently no carbon can be deposited in the form of fat, and the animal cannot thus be fattened. Hence the necessity for the addition of peas, beans, or grain, which, for equal weights, contain from 3 to 7 times as much carbon. It is self-evident that a certain amount of fat in the food, contributes to increase the production of fat in the animal. The favorable action of oil-cake (derived from oily seeds), on the fattening of animals, and the influence of fat (as of cod's liver oil) on the production of fat in man, are universally known.

which is a consequence of the production of Carbonic Acid, is determined by a new arrangement, or by a change of position in the atoms of the Sugar.

In the formation of fat, carbonic acid is set free, the oxygen of which is not derived from the atmosphere.

Only in the case of the carbonic acid being ready formed in the sugar or starch, could the separation occur without the disengagement of heat; but if the carbon and hydrogen were present in any other form in the starch (or in the compound from which the fat was produced), it is obvious that a change in the arrangement of the atoms must have occurred, in consequence of which the atoms of the carbon and of the hydrogen have united with those of the oxygen, to form carbonic acid and water.

Now, so far as chemical researches have gone, our knowledge of the constitution of starch, and of the varieties of sugar, will justify no other conclusion that this, that these substances contain *no ready formed carbonic acid.*

Disengagement of heat in similar processes.

We are acquainted with a large number of processes of Metamorphosis of a similar kind, in which the elements of carbonic acid and water are separated from certain pre-existing compounds, and we know with certainty that all these processes are accompanied by a disengagement of heat, exactly as if the carbon and hydrogen combined directly with oxygen.

Such a disengagement of carbonic acid, for example, occurs in all processes of fermentation or putrefaction, which are, without exception, accompanied with the generation of heat.

In the fermentation of a saccharine solution, in consequence of a new arrangement of the elements of the sugar, a certain part of its carbon and oxygen unites to form carbonic acid, which separates as gas; and as another result of this decomposition, we obtain a volatile combustible liquid, containing little oxygen, namely, alcohol.

If we add to 2 equivalents of sugar, the elements of 12 equivalents of water, and subtract from the sum of the atoms 24 equivalents of oxygen, there remain 6 equivalents of alcohol.

$$(C_{24}\,H_{24}\,O_{24} + H_{12}\,O_{12}) - O_{24} = C_{24}\,H_{36}\,O_{12} = 6 \text{ eq. alcohol.}$$

These 24 equivalents of oxygen suffice to oxidize completely a

third equivalent of sugar; that is, to convert its carbon into carbonic acid and its hydrogen into water, and by this oxidation we recover the 12 equivalents of water supposed to be added in the former part of the process, exactly as if this water had taken no share in it.

$$C_{12}\,H_{12}\,O_{12} + O_{24} = 12\,C\,O_2 + 12\,H\,O.$$

According to the ordinary view, 12 equivalents of carbonic acid separate from 3 of sugar, yielding 6 of alcohol; that is, exactly the same amount of these products as if two-thirds of the sugar had yielded oxygen to the remaining third, so as completely to oxodize its elements.

$$C_{36}\,H_{36}\,O_{36} = C_{24}\,H_{36}\,O_{12} + 12\,C\,O_2.$$

By a comparison of these two methods of representing the same change, it will easily be seen that the division or splitting of a compound like sugar into carbonic acid, on the one hand, and a compound containing little oxygen, on the other, is in its results perfectly equivalent to a separation of oxygen from a certain portion of the compound and the oxidation or combustion of another portion of it at the expense of this oxygen.

Heat given out in the vinous fermentation.

It is well known that the temperature of a fermenting liquid rises; and if we assume that a hogshead of wort, holding 1,200 litres=2,400 lbs. French weight, contains 16 per cent. of sugar, in all 384 lbs., then, during the fermentation of this sugar, an amount of heat must be generated equal to that which would be produced by the combustion of 51 lbs. of carbon.

This is equal to a quantity of heat by which every pound of the liquid might be heated by 297·9°; that is supposing the decomposition of the sugar to occur in a period of time too short to be measured. This is well known not to be the case: the fermentation lasts five or six days, and each pound of liquid receives the 297·9 degrees of heat during a period of 120 hours. In each hour there is, therefore, set free an amount of heat capable of raising the temperature of each pound of liquid 1·4 degree; a rise of temperature which is very powerfully counteracted by external cooling and by the vaporization of alcohol and water.

XXII.

Relation of the production of fat to respiration,

From the study of the conditions, which must be united in order to the conversion of Sugar or Starch into fat, it appears plainly, that the formation of Fat stands in a very definite relation to the respiratory process.

Without the aid of the oxygen of the air, no oxide of glyceryle and no fatty acid can be formed from sugar.

In the organism of an animal, in which the other conditions for the production of fat are united, the quantity of fat increases when the oxygen absorbed by the lungs and skin in a given time does not suffice to convert into Carbonic Acid and Water the elements of the non-nitrogenized constituents of the food. The Carbon and Hydrogen of the Sugar and Starch are then deposited in cells in the form of Oil or Tallow.

to the amount of oxygen absorbed.

From the formulæ by which (p. 76) the formation of the fatty acids from sugar was illustrated, it appears, that for 4 volumes of oxygen added to the elements of the Sugar, there are given out, in the form of Carbonic Acid, in the conversion of Sugar into Butyric Acid 8 volumes, in the formation of Caproic Acid 12 volumes, and in that of Caprylic Acid 16 volumes of Oxygen.

It is consequently clear, that, where an animal, in whose body the formation of fat from sugar goes on, respires in an atmosphere containing a known quantity of oxygen, for each volume of oxygen which is taken into the blood and takes a share in the conversion of sugar into fat, twice, thrice, or four times its volume of oxygen is returned to the atmosphere in the form of Carbonic Acid; and the case is therefore possible, that the air in which an animal respires may increase in volume. The amount of this increase has a certain relation to that of the oxygen retained in the fat. It is further obvious, that in an animal in whose body fat is formed from non-nitrogenized substances, the heat set free is not directly proportional to the amount of oxygen absorbed from the air, but is greater by a certain amount.

Experience teaches us, that in poultry, the maximum of fat is obtained by tying the feet, and by a medium temperature. These

animals in such circumstances may be compared to a plant possessing in the highest degree the power of converting all food into parts of its own structure. The excess of the constituents of blood forms flesh and other organized tissues, while that of starch, sugar, &c. is converted into fat. When animals are fattened on food destitute of nitrogen, only certain parts of their structure increase in size. Thus, in a goose, fattened in the method above alluded to, the liver becomes three or four times larger than in the same animal when well fed, with free motion, while we cannot say that the organized structure of the liver is thereby increased. The liver of a goose fed in the ordinary way is firm and elastic; that of the imprisoned animal is soft and spongy. The difference consists in a greater or less expansion of its cells, which are filled with fat.

In some diseases, the starch, sugar, &c. of the food obviously do not undergo the changes which enable them to assist in respiration, and consequently to be converted into fat. Thus, in diabetes mellitus, the starch is only converted into grape sugar, which is expelled from the body without being applied to any purpose in the system. It is conceivable, that in some diseases, Sugar and Starch may be advantageously replaced, as elements of respiration, by fermented liquors and solid or liquid fats.

In other diseases, as for example in inflammation of the liver, we find the blood loaded with fat and oil; and in the composition of the bile there is nothing at all inconsistent with the supposition that the liver takes a certain share in the formation of fat and in the transformation of sugar and starch into fat; or that, under certain conditions, some constituents of the Bile may be metamorphosed into fat.

XXIII.

Division of the constituents of food.

According to what has been laid down in the preceding pages, the substances of which the food of man is composed may be divided into two classes; into *nitrogenized* and *non-nitrogenized*. The former are capable of conversion into blood; the latter incapable of this transformation.

Out of those substances which are adapted to the formation of blood are formed all the organized tissues. The other class of substances, in the normal state of health, serve to support the process of respiration. The former may be called the *plastic elements of nutrition;* the latter, *elements of respiration.*

Among the former we reckon—

Vegetable fibrine.
Vegetable albumen.
Vegetable caseine.
Animal flesh.
Animal blood.

Among the elements of respiration in our food, are—

Fat.	Pectine.
Starch.	Bassorine.
Gum.	Wine.
Cane Sugar.	Beer.
Grape Sugar.	Spirits.
Sugar of Milk.	

XXIV.

The most recent and exact researches have established as a universal fact, to which nothing yet known is opposed, that the sulphurized and nitrogenized constituents of vegetable food, so often mentioned, have a composition identical with that of the constituents of the blood.

No nitrogenized compound, the composition of which differs from that of fibrine, albumen, and caseine, is capable of supporting the vital process in animals.

The animal organism unquestionably possesses the power of forming, from the constituents of its blood, the substance of its membranes and cellular tissue, of the nerves and brain, of the organic part of cartilages and bones. But the blood must be supplied to it ready formed in every thing but its form—that is, in its chemical composition. If this be not done, a period is rapidly put to the formation of blood, and consequently to life.

Gelatine unfit for producing blood.

This consideration enables us easily to explain how it happens that the tissues yielding gelatine or chondrine, as, for example, the gelatine of skin or of bones,

are not adapted for the support of the vital process; for their composition is different from that of the fibrine or albumen in the blood.

For the same amount of Carbon, Gelatine contains more Nitrogen, Hydrogen, and Oxygen than the constituents of blood. We may suppose, that by the separation of a certain quantity of these elements from the gelatine, a body may be obtained, which, in reference to the proportion of Carbon, Nitrogen, Hydrogen, and Oxygen, shall have a composition identical with that of the constituents of blood; but, so far as our knowledge extends, we are not acquainted with any process in the organism by which such a compound could be supplied with the Sulphur, in which it is deficient.

Change of matter in the gelatinous issues.

The gelatinous tissues, the gelatine of the bones, the membranes, the cells, and the skin, suffer, in the animal body, under the influence of oxygen and moisture, a progressive alteration; a part of these tissues is separated, and must be restored from the blood; but this alteration and restoration is obviously confined within very narrow limits.

While, in the body of a starving or sick individual, the fat disappears, and the muscular tissue takes once more the form of blood, we find that the tendons and membranes retain their natural condition; the limbs of the dead body retain their connections, which depend on the gelatinous tissues.

Disappearance of gelatinous substances in nutrition.

On the other hand, we see that the gelatine of bones devoured by a dog entirely disappears, while only the bone earth is found in his excrements. The same is true of man, when fed on food rich in gelatine, as, for example, strong soup. The gelatine is not to be found either in the urine or in the fæces, and consequently must have undergone a change, and must have served some purpose in the animal economy. It is clear, that the gelatine must be expelled from the body in a form different from that in which it was introduced as food.

They serve for the reproduction of the gelatinous tissues.

Hence the opinion is not unworthy of a closer investigation, that gelatine, when taken in the dissolved state, is again converted, in the body, into cellular tissue, membrane and cartillage; that it may serve for the repro-

duction of such parts of these tissues as have been wasted, and for their growth.

They save as much blood as would be required for their formation.

The uniform experience of practical physicians shows that gelatinous matters in a dissolved state exercise a most decided influence on the state of the health; and if we reflect, that the food consumed by the sick or convalescent serves for the renovation of the expelled or altered tissues; if we look on it as an undeniable truth, that this renewal and restoration takes place by means of the blood; if, therefore, a part of the blood formed in a limited time is employed in the body of the sick patient for the formation of cells and of the substance of membranes, and this part thereby loses its capacity of becoming muscular fibre, or of serving other vital objects, then it is clear, that, by the presence of dissolved cells and membranes in the food, if they really possess the power of again assuming, in the organism, their original form, that in this case, their use is followed by a true saving of blood, of time, and of force.

XXV.

Conversion of grape sugar and sugar of milk into carbonic acid and water.

In the conversion of Grape Sugar and Sugar of Milk (C_{12} H_{12} O_{12}) into Carbonic Acid and Water, 24 eq. of oxygen are added to their elements. Of these, 12 eq. combine with Hydrogen to form Water, 12 other equivalents take the place of the hydrogen, and we obtain 12 eq. of carbonic acid, which contain 24 eq. oxygen, that is ultimately, the very same products as if the 12 eq. of carbon in the Sugar had combined directly with 24 eq. of oxygen.

The volume of the air, in this process, remains unchanged.

Now since Carbonic Acid contains its own volume of oxygen, it is evident, that in the conversion of Sugar into Carbonic Acid in the animal body, for a given volume of oxygen which combines with the elements of the Sugar, an equal volume of Carbonic Acid must be be separated; and that the volume of the air, in which the animal respires, cannot, under these circumstances, undergo any alteration. The same takes place with all other elements of respira-

tion containing Carbon, Hydrogen, and Oxygen, the two last in the proportion to form Water.

Alcohol, when in the human body it is converted into Carbonic Acid and Water, requires for this purpose 12 eq. of oxygen; and there are produced 4 eq. Carbonic Acid and 6 eq. of Water.

It is diminished in the case of alcohol,

The air in which a man breathes, in whose organism the elements of alcohol are employed for respiration, must consequently diminish in volume. For every 12 volumes of Oxygen, taken up by the blood from the atmosphere, only 8 volumes are returned to the air in the form of Carbonic Acid, while 4 volumes are given out in the form of Water, and disappear as far as measurement is concerned, since they lose the gaseous form.

and of fat.

A similar result is obtained in the case of Fat. Assuming the formula $C_{11}H_{10}O_1$ as the nearest expression of the analysis of fatty bodies in general, a quantity of fat, corresponding to that formula, requires, for complete conversion into Carbonic Acid and Water, 31 volumes of Oxygen.

Amount of diminution of volume in the case of fat.

For 31 volumes of Oxygen, which must be taken up by the blood for the complete oxidation of the above quantity of fat, only 22 volumes are returned to the air in the form of Carbonic Acid Gas (21 vol. with 1 vol. existing in the fat, sufficing to convert into Carbonic Acid the 11 eq. of Carbon in the formula of fat), while 10 volumes, being converted into water, disappear. Consequently, the volume of the air in which a carnivorous animal inspires, whose respiration is kept up at the expense of the elements of fat, must also diminish.

In that of alcohol.

In the case of Alcohol, the Oxygen absorbed is to that given out in the form of Carbonic Acid as 3 : 2; in the case of Fat, the proportion of the carbonic acid given out is somewhat larger. In both cases the volume of oxygen, which, in consequence of assuming the form of water, disappears, is to that given out in the form of Carbonic Acid, nearly as 1 : 2.

In that of organic acids.

The organic acids taken into the organism in the form of tartrates, acetates, or malates, are converted into Carbonic Acid and Water. For the conversion of Tartar (acid Tartrate of Potash) into Bicarbonate of Potash, 10 eq. of

oxygen must be added to its elements, and the result is, the formation of 8 eq. Carbonic Acid and 4 eq. Water.

$$\underset{\text{Tartar}}{C_8H_4O_{10}\left.\begin{matrix}HO\\KO\end{matrix}\right\}} + O_{10} = \underset{\text{Carbonic Acid}}{8CO_2} + \underset{\text{Water}}{4HO} + \underset{\text{Hydrate of Potash}}{KO, HO}$$

$$= \underset{\text{Bicarbonate of Potash}}{(KO, HO, 2CO_2)} + \underset{\text{Carbonic Acid}}{6CO_2} + \underset{\text{Water}}{4HO.}$$

Of the 8 eq. of Carbonic Acid, 2 eq. are given out, in the form of Bicarbonate of Potash, by the urine, while 6 eq. are exhaled through the skin and lungs. Now, since 6 eq. of Carbonic Acid contain 12 eq. of Oxygen, it is evident that the air, in which a man or an animal respires at the expense of the elements of Tartar, must increase in volume. For every 10 volumes of oxygen taken into the system, 12 volumes are given out in the form of Carbonic Acid. Acetic Acid, Citric Acid, and Malic Acid, or rather the salts of those acids, play in the respiratory process the same part as sugar or starch; for every volume of Oxygen absorbed by their elements, an equal volume is returned to the air through the skin and lungs in the form of Carbonic Acid.

In the case of the constituents of blood.

If we assume, that the constituents of blood in the food of an animal are employed for respiration, and are converted into Urea, Carbonic Acid, and Water, then it follows, from their known composition, that of 100 volumes of Oxygen which are taken up by the blood and employed in the formation of the above products, only 84 volumes are returned to the air in the form of Carbonic Acid, while 16 volumes disappear, being converted into Water.

From these considerations it is plain, that the volume of the air, in which men or animals respire, must, under ordinary circumstances, be diminished. In the carnivora, in whose bodies the respiratory process is kept up at the expense of the elements of both the fat and the fibrine, albumen, &c. of their food, the oxidation of both of these, in the herbivora, only the oxidation of the latter, determines a diminution of volume. It is only during the formation of Fat in the bodies of herbivora, or when respiration is carried on at the expense of the elements of Tartaric Acid, that exceptions occur, the volume of the air, in these cases, being in-

creased; and this increase of volume may possibly suffice, in many cases, to counteract the diminution of volume caused by the formation of water, so far, at least, that the absorbed oxygen appears equal in volume to that given out in the form of Carbonic Acid.

The exact quantitative determination of the loss of volume in air, in which a carnivorous or herbivorous animal respires, would lead to a more accurate theory of the respiratory process than we possess at present. It is probable, that by this means, we may be enabled to ascertain in what proportion the non-nitrogenized elements of food and the constituents of blood take part in that process.

XXVI.

Conditions under which the weight of the body is constant.

If all parts of the living animal are to maintain entirely unchanged their condition and structure, or to recover these in a given time, the food, in nature and quantity, must be equal to the matters consumed and expelled from the body by the action of oxygen. The supply of the constituents of blood and of non-nitrogenized elements of respiration must be in proportion to the previous waste.

In each individual, there occurs, from day to day, indeed from one hour to another, a continual variation in the waste; inasmuch as the condition of bodily or mental exertion and labor, motion and rest, is never constant. This explains the necessity of a change in the amount and nature of the food, and the impossibility of fixing an unalterable measure of food, to furnish the supply daily required. This will appear the more obvious, when we reflect, that the kidneys, the skin, and the lungs, cannot be the only channels through which the products of the change of matter pass out of the system: and that the intestinal canal acts as an organ of secretion, the relation of which to the respiratory process cannot be overlooked.

The intestinal canal is an organ of secretion.

The fæces.

If, in point of fact, the amount of oxygen taken up in a given time exactly suffices to convert the existing products of the change of matter into Urea, Carbonic Acid, and

Water, and the existing non-nitrogenized elements of respiration into Carbonic Acid and Water, in exactly the same time, then it is only the undigested or indigestible constituents of the food which can be given out of the body through the intestinal canal.

They contain undigested matters.

With reference to the presence of undigested matters in the intestinal canal, observations are recorded, according to which the fæces, in certain diseases, contain recognizable remains of food, as starch, portions of flesh, &c.; but, since no part, however small, of the nitrogenized or of the sulphurized and nitrogenized constituents of the food of man is incapable of being dissolved, we must, as a general rule, assume, that all these substances have been digested, that is, dissolved; for a property belonging to the parts must also belong to the whole.

The nitrogenized constituents in the fæces are products of the change of matter.

In these cases it is hardly to be doubted that, when nitrogenized substances are to be found in the fæces, and their presence has been demonstrated by all the analyses hitherto made, these substances can only be, either products of the change of matter in the intestinal canal itself, or products of the general change of matter, which have not undergone the normal changes, and which are separated from the blood, in virtue of a power belonging to the intestinal canal, or to some portion of it.

The function of the intestinal canal is to restore equilibrium.

The apparent deficiency or absence of any structure in the intestinal canal, by means of which this secretory process is effected, is opposed to the opinion, that a true circulation, attended by the restoration of the disturbed equilibrium in the organism, goes on there; but the following considerations may perhaps serve as a support to that opinion.

Relation of the secretory effect of the intestinal canal to the oxygen taken up.

It is plain that the secretory effect of the intestinal canal, the amount of matters separated from the blood by its action, must stand in a definite ratio to the amount of oxygen taken up and consumed by the individual; or, what comes to the same thing, to the amount and composition of the food. Every change in the relative proportion of blood-constituents and non-nitrogenized elements of respiration in the food, must exert an influence on the quantity and on the composition of the fæces.

If we assume, that the food contains a larger proportion of blood-constituents than is required for the supply of the waste of matter in the body, then the excess of these constituents must augment the mass of blood, or, if the animal possess the necessary assimilative power, the mass of flesh in the body. If the amount of oxygen taken up be exactly sufficient to convert into oxidized products in a given time the products of the change of matter present in the system, as well as the elements of respiration contained in the food, then the fæces must possess the normal composition and character. But if the amount of sugar or of fat introduced in the food be greater than the oxygen supplied in an equal time can completely convert into carbonic acid and water, then, in an animal, possessed of the necessary power, a part of the sugar will be converted into fat; and this fat, along with the fat introduced in the food, will go to increase the quantity of fat in the body.

Relation of the fæces to the food, with a sufficient supply of oxygen;

If we now suppose that the products of the change of matter and the non-nitrogenized elements of respiration possess an equal attraction for the oxygen with which they combine in the organism, it is evident, that the oxygen present must be divided between them. A certain portion of oxygen will unite with the sugar, or with the elements of the non-nitrogenized elements of respiration; another portion will combine with the elements of the nitrogenized products resulting from the change of matter. When the supply of oxygen is deficient, or, what comes to the same thing, when there is an excess of non-nitrogenized and nitrogenized elements of respiration (the latter being always viewed as the products of the change of matter), their normal conversion in[to o]xidized compounds must necessarily appear impeded.

with a deficient supply of oxygen.

Sugar, when oxygen is wanting, may pass into fat: but only a part of the products of the change of matter can be, under these circumstances, converted into the normal oxidized compounds. While, in the normal state of nutrition, of waste and restoration, and of the supply of oxygen, the nitrogen of the effete tissues takes the form of urea, and the sulphur of the bile that of sulphuric acid, which are discharged in the urine; when

When the elements of respiration are in excess, a part of the products of the change of matter is secreted by the intestinal canal.

there is a deficiency of the oxygen necessary to the formation of these products, uric acid, a compound much richer in carbon than urea, will be formed, a part of the sulphur will appear in the urine as cystine (cystic oxide), or in some other form; and the excess of the products of the change of matter, which has not undergone these changes, must either remain in the blood, or it must, as we know of no other exit for it, be evacuated by the intestinal canal.

Normal fæces.

The fæces of a person who in his daily food has introduced a certain quantity of flesh, bread, and fat, exactly corresponding to the available supply of oxygen, and in the proportion which is precisely necessary, in order, during twenty-four hours, to preserve and restore the normal condition of every part of his body, can only contain the indigestible or insoluble ingredients of his food, accompanied by such matters as have been secreted in the intestinal canal. The quantity of the fæces will bear a direct relation to that of these indigestible matters and intestinal secretions. If, now, the same individual adds to his daily ration a certain amount of alcohol in the form of wine, beer, or spirits; if, consequently, his daily supply includes an excess of a substance (alcohol), of which we know that its elements, in the circumstances under which they are exposed to the action of oxygen in the system, possess a far stronger attraction for oxygen than, for example, fat; then, it is obvious, that the elements of the alcohol, and not those of the fat, will combine with the oxygen. If the amount of oxygen taken up remain the same, then fat will be deposited in the body, or it will go to increase the amount of fat in the blood, or it must be expelled from the body through the intestinal canal.

Influence of the food on the nature of the fæces;

on the quantity of the fæces.

In the same way, by the presence of alcohol, the change of matter itself, in so far as the oxygen conveyed by the blood has a share in it, or the conversion of the products of the change of matter into oxidized compounds, must be impeded or altered in its form: besides the usual products, there must be formed notrogenized or sulphurized compounds of another kind, which, in the shape of secretions, very rich in carbon and hydrogen, increase the amount of fæces; or, if the normal action of the intestinal canal do not suffice, and be not excited by stimulants, then, by their presence in the blood, the vital process

must undergo a change, which must make itself known in some one of the functions of the body.

Influence of alcoholic drinks.

On the other hand, if a certain amount of alcohol be added to the food, and if the elements of respiration, otherwise necessary, be diminished by a corresponding amount, or the supply of oxygen increased in a corresponding ratio, then the use of alcoholic liquors, without any reference to the effect of alcohol on the nervous system, will exert no unfavorable influences on the normal processes of the organism. .

Views as to the nature of the fæces.

There are two opinions as to the nature of the fæces. According to one view, they consist of the indigestible parts, of certain other ingredients of the food and of the bile, which are in a state of putrefaction, to which they owe their smell: according to the other, they are nothing else than products of an imperfect combustion, of an unfinished oxidation, and may be typified as the smoke and soot of this process.

Those who hold, that the fetid substances in the fæces are ingredients of the food or of the bile, in a certain state of putrefaction, have been chiefly induced to form this opinion by the smell; but the smell which any substance possesses cannot possibly decide in favor of an opinion in science.

The occurrence of recognizable remains of the food in cases of what is called weak digestion, might be held, *a priori*, as a proof that the soluble constituents of the food which reach the intestinal canal undissolved, in consequence of a want of the conditions necessary for their solution, are expelled from the system, without passing into putrefaction. We may further suppose, that in reference to the dissolved matters, the blood may be, as it were, in a state of saturation; but all this cannot be made available in favor of the supposition that the fæces are in a state of putrefaction.

The constituents of the food, whether non-nitrogenized, or containing nitrogen and sulphur, pass into putrefaction out of the body: but in no period of that putrefaction has any product been as yet observed, which has the smallest analogy, in regard to smell, with the fæces.

The putrefaction of the sulphurized and nitrogenized constituents (blood constituents) of food, makes itself known at all times,

and under all circumstances, by a disengagement of ammonia; when by themselves they assume, in this condition, an alkaline reaction. The putrefaction or fermentation of non-nitrogenized substances is always accompanied by the formation and separation of carbonic acid or of an organic acid, such as acetic or lactic acid.

They contain in the normal state neither fermenting nor putrefying matters.

If the fæces contained putrefying or fermenting ingredients, such ingredients must be recognizable either by an acid or an alkaline reaction; but the fæces of healthy persons, children as well adults, are thoroughly neutral. They contain occasionally, as an accidental ingredient, the double phosphate of magnesia and ammonia, which is consumed in bread, but, with this exception, no ammoniacal salts. Alkalies do not disengage ammonia from the fæces.

Fresh fæces cause no fermentation in solution of sugar.

Finally, if the fæces were in a state of putrefaction, that state must be communicable to sugar; but healthy fæces, provided they are preserved from contact with the air, cause no fermentation in a solution of sugar.

When air is admitted, they enter into putrefaction,

In relation to the air, the fæces are analogous to urine, which, if air be excluded, may be preserved for months in clean vessels, without putrefying or disengaging ammonia, while, if air be admitted, the urine absorbs oxygen with great rapidity. The oxygen of the air unites with a substance contained in urine, which is very prone to change; and it is the decay or eremacausis of this compound, and not at all, as is commonly supposed, the presence of a ferment in the urine, by which the urea is transformed into carbonate of ammonia. In consequence of the absorption of oxygen, there is formed in the urine at the same time a certain quantity of acetic acid, which cannot be detected in fresh urine.

The fæces, when collected out of contact with the air, retain their color; when air is admitted, their surface becomes darker, and with this change of color, they pass into fermentation and putrefaction. As, in the healthy organism, the constituents of the urine are never found in a state of putrefaction, even so it is impossible to suppose that state to exist in the healthy fæces.

as the urine does.

Relation of the fæces to the elements of respiration in the carnivora;

When the organic constituents of the food of a carnivorous animal are capable of entering into the circulating fluid without residue, when they are entirely applicable to the vital process, then the secretions or excretion of the intestinal canal, and the amount of carbon and hydrogen in the fæces, stand in a very definite proportion to the daily supply of carbon and hydrogen, and to the quantity of oxygen taken up through the blood in the same time.

When the amount of elements of respiration, of fat, sugar, or starch, in the food, is increased, without an increase of the oxygen necessary for their consumption in the body, then the amount of carbon and hydrogen in the fæces, in those individuals in whom the conditions of the formation or deposition of fat are wanting, must increase in an equal proportion.

and in the herbivora.

In herbivorous animals, lastly, the amount of carbon in the fæces bears a certain proportion to the quantity of indigestible or insoluble matters which the food contains. In a wood caterpillar, an animal which consumes a hardly appreciable quantity of blood constituents, the fæces have the form of fine saw-dust, the weight of which, during the day, exceeds that of the animal from three to five times. The weight of the fæces of a horse, fed on hay and chopped straw, is greater than in the case of a cow fed on turnips. The frontiers of the Lower Rhine provinces and of Westphalia, where the bran or husk of the grain is eaten in the bread of the country, may be recognized by the peculiar color and consistence, as well as by the remarkable bulk, of the remains of preceding meals, left by wayfarers under the bushes and hedges.

The complex structure and arrangement of the intestines of herbivorous animals appear to require, for the purpose of increasing the surface of the food, so poor in blood constituents, as well as for the propulsion of the ingesta, a certain proportion between the soluble or digestible and the insoluble or indigestible constituents of the food. A supper of eggs causes in most individuals next day an apparent costiveness; which is perhaps caused by the circumstance that by such food the bulk of the matter destined for excretion by the intestinal canal is not increased.

Character of the fæces in sick and starving persons.

Finally, if we reflect, that in starving persons, in many sick persons, who for weeks take no solid food, the evacuation of the fæces is not suppressed, it can hardly be doubted, that in certain parts of the intestinal canal, a secretion of matters, which the organism in its actual state, cannot change, goes on; and that this can be increased, up to a certain point, by remedies.*

* A series of experiments, which I made on the relations of the fæces to a solution of grape sugar (to which was added tartar, a substance which, according to the experiments of H. Rose, singularly promotes and accelerates fermentation when commencing) have led to the following observations.

The fæces of a sucking child, which, under the microscope appeared to consist for the most part of epithelial cells, swelled by moisture, caused during three days no fermentation in the solution of sugar; on the fourth day bubbles of gas appeared; on the fifth a regular fermentation set in, and the sugar disappeared. By distillation there was obtained a thoroughly well-flavored spirit. As soon as the fermentation set in, the so-called fungi of fermentation appeared.

The fæces of a healthy adult, in two other experiments, produced no fermentation; even after five days.

Those of a second individual, suffering from weak digestion, produced in the saccharine solution by the end of the first day a feeble fermentation, in censequence of which the fæcal smell entirely disappeared. By distillation there was obtained a very small quantity of alcohol of a most offensive smell of putrid cheese. When the same person had taken, fasting, a certain quantity of salt and water, to promote the action of the bowels, and the consequent evacuation was richer in swollen epithelial cells, a perfect fermentation took. place.

Healthy human fæces, therefore, possess the property of exciting fermentation, when they have themselves passed into a state of fermentation or putrefaction; but they acquire this state only after being expelled from the body, and when subsequently exposed to the air. The disappearance during fermentation of their peculiar fetor is itself a fact full of significance with respect to the view to be entertained of their true nature. The disengagement of gases which goes on in the intestinal canal of persons who are out of health, or affected with disease, shows the facility with which the fæcal matters, from causes operating within the body, may pass into a decomposition analogous to putrefaction.

It may perhaps not be unimportant to the decision of the question as to the nature of the fæces, if I direct the attention of the reader to the fact that it is easy, by an imperfect oxidation of albumen, to produce the peculiar substance to which the fæces unquestionably owe their peculiar fetor.

If we heat, in a retort, 1 part of white of egg and 3 of hydrate of potash, so as to melt the mixture, and continue the heat till the disengagement of

ammonia has nearly ceased, and if we then supersaturate slightly the contents of the retort, after cooling, with dilute sulphuric acid, and distil, we obtain, along with a disengagement of carbonic acid and sulphurretted hydrogen, a liquid which is slightly acid (from the presence of acetic and butyric acids), and which has the most horrible fæcal smell. The substance to which the smell belongs is soluble in water and alcohol; it combines with alkalies, without, however, neutralizing them. When exposed to the air it is rapidly changed.

By means of caseine, gelatine, and fibrine, when treated in the same way, we can procure all the different varieties of fæcal odor.

PART II.

THE METAMORPHOSES OF THE ANIMAL TISSUES.

THE

METAMORPHOSES OF THE ANIMAL TISSUES.

THE METHOD.

Development of the natural sciences.

The history of the sciences teaches us that every branch of physical science, in its origin, embraced nothing else than a series of Observations and Phenomena, standing in no demonstrable connection with each other.

Special laws of nature.

By the discovery of new facts, by which two or more of the earlier observations were brought into connection, the conditions of all progress were supplied. Observers attained first to special laws, which included the mutual relations of a certain number of natural phenomena; and next, to general laws, or what is the same thing, certain expressions of the connection or dependence of a large, or of a larger series of observations.

General laws of nature.

Many branches of physical sciences, such as Mechanics, Hydrostatics, Optics, Acoustics, and the science of Heat, rose to the rank of abstract sciences, inasmuch as men succeeded, by a series of rational or logical deductions, in reducing all known cases of the phenomena of motion, or of pneumatics, acoustics, or caloric, to certain truths, or to a very small number of indubitable facts; which not only connected together all previously observed phenomena, but included in themselves all discoverable facts; so that, in order to the explanation of the new phenomena, or observations, a new and isolated series of deductions from experiment was not required, as is the case in the experimental sciences.

If we may assume as an undoubted truth, that not only the

phenomena of what is called dead, or inorganic nature, but also those which are peculiar to animal and vegetable life, stand in certain relations to each other, and are determined by certain causes; if it be true, that we can only attain a clear insight into the real nature of the organic processes, by a knowledge of these causes or conditions, then must the search after the mutual relations, and the mutual dependence of the vital phenomena be regarded as the most important problem of physiology.

The explanation of very many natural phenomena requires, in most cases, nothing more than a knowledge of the relation of dependence in which they stand to one another.

These relations, in every branch of natural science, may be ascertained by extending our experience by accurate experiment and observation; and there can be no question, that, just as chemistry is gradually losing the character of the art of making experiments, so also physiology is capable of assuming the rank of a deductive science.

The course followed in the investigation of natural science.

If, in conformity with the course of investigation in natural science, special laws must precede those which are general; if it appear necessary, to a right comprehension of the phenomena of life, to be acquainted with the organism, not only in reference to the form of all its parts; if, for this purpose, we must ascertain with the utmost accuracy the functions of the individual organs, and the relation of their mutual dependence, the relation of the form to the matter of which it is composed, and the nature of the dependence of the form on the matter which surrounds it; then it cannot surely be denied, that we are still at an infinite distance from the universal and ultimate collective expression or law, which includes the idea of vitality, or the knowledge of the cause and connection of all vital phenomena. We are still so far removed from this, that to many, the supposition of the probability, or even of the possibility of ascertaining such general laws in physiology is incomprehensible; for, to most it is even impossible to separate the vital phenomena of the mind from those of the body, or the idea of vital force from the form of the living structure.

Obstacles to investigation ari-

The man of the most practised intellect cannot withdraw himself from the operation of those laws on which

his power of comprehension depends. If daily observation for a long period has shown him two phenomena, or facts, in close connection; if he has learned that for centuries before his time, they have always been regarded as inseparable; if he has never, at any time, by accident or design, been led to consider each of them by itself, he becomes gradually incapable, even with the greatest effort, of separating them; and the supposition that these two facts are in their nature separable, may become at last unintelligible and incomprehensible to his intellect.

sing from preconceived opinions.

Numberless examples prove, that the wisest and most acute of men have regarded as impossible facts and suppositions, because they were incomprehensible to their understandings; while their posterity have not only found these things comprehensible, but, further, every one now knows them as established and incontrovertible truths.

Men of the profoundest sagacity, and elevated above ordinary notions, were unable to comprehend that gravitation could act upwards instead of downwards, or that the sun, at so great a distance, could exert an influence on the earth, or the earth on the moon. Even the great Leibnitz rejected the views of Newton, because the motion of the planets in curve lines round a common centre appeared to him impossible, without some continually operative mechanism, or the aid of a propelling angel; for, as he thought, according to nature, the moving body, without some such controlling power, must deviate from its path in the direction of the tangent.

Supported by the general principle, that a body can produce no effect in a place where the body itself is not, men rejected the Newtonian doctrine of gravitation; and the notion of the action of gravity at infinite distances, without any intermediate material agency, now familiar to every boy, appeared to the most distinguished men to include so gross a contradiction, that they regarded as far more probable the most singular and the most groundless creations of their own fancy.

A multitude of doctrines in mechanics and physics, which we know to have been discoveries requiring long time, and results of the greatest patience, and of the most laborious exertions and investigations, appear to us now so true and obvious, that, unless we

look to the history of their development, it is incomprehensible to us, that their truth should have been doubted at any time, or by any person. The simple position, that a body once set in motion, would continue, if left to itself, to keep up the same velocity in the same direction, without ever ceasing, to infinity, appeared so contrary to the commonest and plainest experience, that the acknowledgment and establishing of its truth for a long period met with the greatest opposition.

The idea, once prevalent, that two chemically active substances, by their union in indefinite or unlimited proportions, by weight, can produce a compound of definite unalterable characters, now appears to us incompatible with a sound understanding.

We thus perceive that "the comprehensible" has nothing whatever to do with the phenomenon; it depends on the state of development of the intellect. When, to the observer, the connecting link is wanting, which attaches a fact to the ordinary course of thought, then the fact, to his view, is destitute of truth or of comprehensibility. This is one of the greatest obstacles which impedes the application of Chemistry to Physiology, or the simple study of chemical discoveries on the part of many physiologists. To this must be added, in Pathology, the holding for true of observations, the accuracy of which has no other support but this, that they have been held as true for a thousand years. If, in these branches of knowledge, the methods of proof and investigation be not changed, there is no hope that, with all her progress, Chemistry can ever become capable of yielding essential advantages to Physiology and Pathology; and yet it is impossible that these branches can ever acquire a scientific foundation, without the aid of Chemistry and Physic. Every one feels the necessity; it is only concerning the mode of application of these sciences that men are not agreed.

Physiology as a deductive science.

If we require no more detailed argument in favor of the opinion that every empirical science, and Physiology among the rest, may acquire, in the lapse of time, a deductive character, then it must be quite indifferent *whether*, or *what* she borrows from other sciences, in order to attain that rank. We know that Astronomy has now become only a part of the gen-

eral science of motion, and that it is precisely to this circumstance that it is indebted for its scientific foundation.

Investigation of physiological laws.

If we bear in mind, that as no event happens in the world, so also no phenomena occurs in nature, in plants, or in animals, without standing in relation to, or being the immediate consequence of, another which has preceded it; that the actual condition of a plant, or of an animal, is attached to certain conditions which have gone before, then it is clear, that if we were aquainted with all the causes, with their action in time and space, and with their properties, which have determined that condition, we could predict what condition would next follow. The expression of these conditions, or relations, this it is, which is called a natural law.

Distinction between ancient and modern Chemistry.

No one probably, who is historically acquainted with the development of Chemistry, and of many parts of Physics, will fail to perceive that the chief cause of the progress of these sciences has been the gradually acquired conviction, that every natural phenomenon, every state, has more than one determining condition; that every effect has several causes; and it is the simple search after this plurality of causes, it is the separation of the effects, which distinguishes the modern from the earlier Chemistry. In fact, during the phlogistic period, a limit was quickly set to true investigation, by the assumption of a principle of dryness and of moisture, of heat and of cold, of inflammability, of metallinity, of acidity, of volatility, of color, &c. For every property we had a peculiar essence, which explained every thing; the mere description of the phenomenon included the explanation.

The change of weight which bodies exhibit, when subjected to chemical processes, passed for a property of matter, like the effervescence of limestone with acids. For the phenomena of combustion and calcination chemists had their theory; but the examination of the changes thus produced in the weight of bodies, was regarded as foreign to their province. It was left to mechanical philosophers to explain how a body should exhibit a greater weight, after losing an element, than it possessed before; and how bodies in general should vary in weight. The increase

of weight in calcination was an accidental property, which, as was then believed, belonged to metals among other bodies.

Position of many physiologists of the present day.

A number of physiologists and pathologists in regard to the comprehension of the vital processes and phenomena, stand on the level of the old phlogisticians. They ascribe the effects of the nervous system to a nervous force; and Vegetation, Irritability, Sensibility, what are called Action and Reaction, all of them simple effects of motion and resistance, the causes of formation, and of change of form, which are collectively described as the typical forces, are regarded as independent existences, or, at least, in these explanations, occupy the place of the essences of the ancients.

Confusion between an action and its cause.

The commonest phenomena even yet are personified in the minds of many physiologists as peculiar powers, as properties, which they are tempted to explain by peculiar causes, differing from other known causes. Thus the restoration of equilibrium between two fluids of different nature, or two solutions of dissimilar substances, separated by an animal membrane, has obtained the names of endosmose and exosmose, and men regard these names as if they were independent things, while the phenomenon is nothing else than filtration, different from the ordinary one only in so far as that the passage is effected by an attraction (a drawing, an affinity) instead of by pressure.

This mode of viewing nature was accompanied by the not less erroneous notion, that causes resemble their effects, that like must be produced by like. The cause of combustibility was supposed to be something combustible, that of acidity, something acid; the caustic property of quicklime proceeded from a *causticum,* which could be transferred from one body to another, from lime, for example, to the so-called mild alkalies. In the alkalies, chemists supposed the existence of a primitive alkali, in the acids that of an *acidum universale,* in the salts that of a primitive salt. Analogous bodies were varieties of one substance.

False explanations of physical properties.

Many of the physical properties of a body were explained by the physical character of its smallest particles; a pungent taste was ascribed to sharp particles. Lemery's notion that the particles of an acid had the form

of spear-heads with barbs, that those of the alkalies were porous like sponge, met with universal approbation; for the blunting of the acid properties by the alkali, their mutual power of neutralization, were thus perfectly explained: and when gold was precipitated from its solutions by ammonia, this appeared to his contemporaries quite obvious, since they attributed to ammonia the property of breaking off the spear-heads from the shafts. It acts, says Lemery, like a cudgel which a boy throws up into a walnut-tree loaded with fruit. In like manner, an astringent, or cooling action on the living body, was ascribed to certain substances, which have an astringent or cooling taste; and a beverage containing much alcohol, which, in common language is called strong, was introduced into medicine as a roborant or strengthening remedy.

It is a mistake to believe that this mode of regarding natural phenomena belongs to a time long since past. In a recent work (Versuch eimer Allgemeinen Physiologischen Chemie, Braunschweig, bei Vieweg, 1844, No. I. p. 7), the following passages prove that it is in operation at every moment in the minds of many physicians of our time:—"We thus conclude justly," so says Mulder, "that in Sulphur, Selenium, Chromium, and Manganese, similar forces are present, and we are naturally led to the conclusion, that the chemical character is independent of the material nature of the elements, but dependent on the forces which govern the molecules of Sulphur, Selenium, &c. Thus into the notion of Sulphur, there comes something of the idea of force, and indeed of the same force, which is also active in Selenium; active, not only in producing compounds, but in assisting to determine their leading characters. Even in more remote compounds this force of Sulphur and Selenium shows its activity."

The beautiful researches of Mitscherlich and Kopp, on Isomorphism, have thus, as we see, been unable to remove the impressions left by the mode of viewing natural phenomena above alluded to.

Every natural phenomenon has more than one cause.

The truth of many opinions or views may be doubted, whether justly or not is here indifferent; but a phenomenon, an effect by itself, which may be perceived everywhere, and at all times, with sound organs of sense, by the

most widely different individuals, cannot be denied. It is only in regard to the causes by which the effect is produced, that doubts can exist. These causes may be quite unknown; but they can never, in the province of natural science, be ascertained by the power of imagination; for we know that one and the same effect, as mechanical motion, a blister on the skin, or the contraction of a muscle, may be produced by various causes, and that one and the same cause can produce a multiplicity of effects.

Chemical combination.

We know that the simple act of chemical combination depends on at least three causes, or conditions, which must bear a certain relation to each other, if the combination is to take place; we know that Affinity, Cohesion, and Heat have an equal share in the process.

Heat is the cause of three different states.

We know, further, that, if a given amount of heat expands the solid body, and forces its particles to recede from one another, a double or treble quantity entirely changes the properties of the body; and that a new change in these properties again occurs, if the amount of heat applied reaches a certain point.

It is quite certain, that Expansion, Liquefaction, and Gasification, have been determined by one cause, namely, by Heat, but that the effects produced are not at all proportional to the cause; the origin of this we have, with the greatest propriety, sought in the opposition or resistance of another cause, and thus has our notion of the nature of the cohesive force acquired a scientific foundation.

Decomposition.

Heat, which is the condition under which the union of mercury with the oxygen of the air is effected, produces the very opposite effect, the resolution of oxide of mercury into mercury and oxygen gas, if the temperature be raised a few degrees.

By a simple process of oxidation, we obtain, from alcohol, acetic acid; the same acid is formed by the oxidation of salicylite of potash; it may be produced from wood, sugar, and starch, by the mere application of heat, the oxygen of the atmospherical air being entirely excluded. In all these cases the product is identical, but the conditions of its formation are singularly varied.

If it be true that a scientific foundation for physiology can only be attained by the investigation and determination of the multiplicity of conditions, on which the phenomena of vitality depend; that the first problem of the modern physiologist is, to distinguish the vital effects and the causes by which they are produced, then it is certain, since a number of causes have, or may have, a share in producing these effects, that the physiologist must possess an intimate and familiar acquaintance with all the forces and causes which in nature are capable of bringing about motion, or a change of the form and structure of matter. How else could he distinguish the effects produced by these causes from those which must be ascribed to a cause that, in its manifestations, has nothing in common with Gravitation, Affinity, &c.?

The separation of vital effects is a chief condition of progress in physiology;

No one can doubt, that these principles of investigation are applied even in the physiology of the day. In fact, the difference between the prevalent mode of viewing nature, and that of the mechanical school which preceded it, is very great; but the influence of the latter, in Germany at least, is very far from being destroyed. With all our recognition of the principles of exact science, we are too ready to cast off her rules, and everywhere, when we do not see our way clearly, our unfettered thoughts plant a forest of errors before the gate of knowledge. The antitheses and paraphrases, formerly so popular, now, as formerly, play the chief part in all explanations, and deprive the description of very common facts or conditions, of the simplicity and clearness of which they are susceptible. The fault lies, not in the principles, but in the want of a rigid adherence to those principles.

but this is neglected in practice.

Some instances, from the writings of a distinguished pathologist of the present day, will perhaps suffice to justify these assertions, and to show the influence which the earlier method of treating science still exerts on that now prevailing. They will show how difficult it is, proceeding from undefined notions, to attain just conclusions; and how insignificant is the gain to science, even in the case of men of the finest intellect, when they renounce the aid of chemical and physical knowledge.

Examples.

Undefined notion of irritation and stimuli.

Thus, for example, a number of external causes, such as Air, Heat, Electricity, Magnetism, Chemical Agents, Mechanical Pressure, Friction, &c., produce, on the organism, or on certain parts of it, certain effects, which in many cases are analogous, in others different. Like all effects, these also are determined, on the one hand, by a certain amount of the acting external cause, and on the other by the amount of those causes which are in activity in the organism, which oppose a resistance (that is, a force) to the action of the external causes. The existence of such causes, acting in the organism, may be determined, and their amount measured by the qualitative or quantitative difference of the effects produced by the external causes, which are marks of an altered condition. The forces at work in the organism may consequently be ascertained by the investigation of those effects which have been qualitatively or quantitatively determined by each external cause, considered by itself. The method of modern pathology is, as is shown by some passages from the celebrated work of Henle (Pathologische Untersuchungen, Berlin, 1840), the exact opposite of the method just mentioned. "Irritation" (or a stimulus, Reiz, German,) "is (according to Henle), every thing, which, acting on the organic substance, alters its form and composition, and therefore its function." (P. 223.) Far from considering the separation or distinction of the various causes and their effects, as the indispensable aid to knowledge, we see here all imaginable causes of a change of form and composition in the organism, lumped together under the word Irritation, or Stimulation, and in the explanations of the different states of the organism this word now plays the part of a thing existing independently, although by it is meant neither the mode of action of electricity, nor that of heat or light, of chemical forces, or of magnetism, but only a small fraction of the action of each of these agents. We have only to substitute, for example, for the word Irritation, in the following passage, the definition above given by the author, in order at once to see what gain has accrued to the science from this method.

"Irritation (Reiz) alters the nervous fibres and their proportion to the blood, but when it does not entirely destroy them, the

change of matter continues: nay, it is perhaps rendered more active by the irritation (or stimulus) applied," &c.

False analogies.

After this, no one will be surprised to find, at p. 221 of the same work, *a hypothesis of the mode of action of stimuli*, in which, however) there is not the most distant allusion to the mode of action af any thing or cause whatever, which, acting on the organic body, alters its form and composition. The following explanation of the relations of the organism to stimuli is characteristic (p. 219). "What the organic body properly is, is the continuance in a state of change, the progress towards a defined object, and up to that object. It is not reaction which is characteristic, but the cessation of reaction. The organic body is not distinguished by this, that it is susceptible of irritation and of change, but by this, that the changes are balanced, and through all changes the organism develops itself according to inherent laws; for the string, whose pitch has been raised by the irritation of a mechanical pressure, continues to sound the higher note as long as the pressure continues; and the metal which has been made elastic by being alloyed, continues alloyed and elastic. But the organic body ceases to react, even if the irritation continue, and when a chemical influence has altered its substance, and thus increased or diminished its activity, the normal composition, and the normal degree of activity returns after a longer or shorter time. How this occurs, I will illustrate by an image. Let us suppose a vessel full of water, into which as much fresh water is introduced on one side as flows out on the other. Let us irritate this water chemically, by throwing, for example, a handful of salt into it. On this irritation the water reacts by a salt taste, at first strong, and then weaker and weaker, and when at last the whole water has been renewed, not a trace of salt will be found in the vessel. This image, coarse as it is, applies exactly to our case, &c."

The author proceeds, as is easily seen, in his explanations and expositions, as far as their form is concerned, just as the mechanical philosopher does. He explains the characters of the organic body, by endeavoring to show its similarity or dissimilarity to other known substances. He tries to obtain an explanation of the peculiarity of a phenomenon by looking for, and comparing with it, similar phenomena, produced by known causes. The natural

philosophy both of the ancients and of the moderns has never despised this method. Errors in it were only committed, when men compared the phenomena to be explained, and endeavored to connect them, with others, to which they bore no real relation; and when they supposed the causes of similar phenomena, especially of those which are very frequently observed, to be known, because they were so familiar to the observation, but without really knowing them. No real insight can be gained by apparent analogies, that is by images.

Examples of false comparisons.

Henle calls the pressure on the string, which raises the pitch, a stimulus or irritation (Reiz), as, in general, according to him, all imaginable changes of form, structure, and composition, proceed from stimuli. Now the pressure has no direct relation whatever to the character of the note, since it only serves to shorten the string for the moment. So, also, metals do not become more elastic by being alloyed, because this property is independent of composition. Between a sounding string, an alloy, and water to which salt has been added, and an organic body, there are no relations of likeness or unlikeness. The water, the constituents of which are oxygen and hydrogen, is not changed in its form or composition; it is not stimulated, and does not react by a saline taste, just because water has no taste.

The organic body cannot be regarded as an exception to a great natural law; it cannot cease to react, if the cause continue in operation, which alters its form and composition, and consequently its function; and when, by a chemical influence, its substance has been changed, the normal composition does not return in it or in the substance which has undergone change. In the language of the mechanical philosopher, the image selected by Henle would be interpreted as follows:—As water can flow out of a vessel constantly supplied with that liquid, without change of level, so the vital phenomena of the animal body continue, as long as it possesses the means of replacing loss from without. An external influence may, for a time, change the vital manifestations, just as salt, thrown into the running water, for a time affects its taste. But as the saline taste gradually disappears, when no more salt is added, so the changed vital manifestations come to an end, when the causes do not continue which produced them, and the normal

functions can again take their proper place. Thus expressed, it is easy to see that the action of the body has nothing to do with the stimulus. Under the given conditions, the level of the fluid in the vessel would have been preserved without the addition of salt, the water originally in the vessel would have been renewed and replaced by different water. So it is with the organic body; if the external supply fail, one of the means of its renewal and preservation is diminished; as the level of the water sinks, when water flows out, without being replaced. A portion of skin, destroyed by red-hot iron, or by sulphuric acid, is renewed, not in consequence of a reaction, but because, under it, a cause of renovation is at work, the activity of which is not called forth by the iron or the acid; for it would have acted, even had those bodies never come in contact with the skin. Nor have the iron and the acid any share in its acceleration, which again depends on other causes.

Typical force, an undefined notion.

It cannot be regarded as a just view of certain vital manifestations, as, for example, the development of the organism from the egg or germ, or the restoration of the original form, when we ascribe to them, as their cause, an idea operating in the organism, and reproducing itself, a typical force, just because these expressions are nothing else than modes of designating the phenomena; and that the salamander restores entire limbs, while in the wounded frog, as in higher animals, the regeneration is limited to a few parts, this as Henle thinks (Rationelle Pathologie, p. 129), cannot be explained by the eternal typical laws which, according to him, exist, because this form of expression says nothing more than that these things take place so, and not otherwise, because they take place so, and not otherwise. The idea of explanation includes a knowledge of the laws; and the idea of law is inseparable from the knowledge of quantitative or qualitative relations.

A rude image of the organism, in many of its relations, may be found in the great sea-going steam-vessels. These consume, at each moment of their voyage, oxygen and fuel, which are given out in the forms of carbonic acid, water, and soot or smoke. In them exists a source of heat and a source of power, which produces motion, or prepares the food of the crew; and when a sail is torn, there is a man at hand to repair it; a leak is stopped by

the carpenter; blacksmiths, and other hands are active, to preserve the ship in her original state and in motion. So, also, in the living body, there are smiths and carpenters at work, and the problem is to acquire a knowledge of them, and of their mutual relations.

Light, viewed as a stimulus.

Finally, if, as with many pathologists, there are included under one word, as, for example, Irritation, forces which really alter the form and composition of the organic body, along with such as do not possess this power, as light, sound, &c., then it is no longer possible for us to understand one another. Light, in itself, is a phenomenon of motion, and is perceived as such by the eye, because it excites motion in the optic nerves, which is communicated to the sense of sight. The motion once begun is propagated, as the note of a flute, propagated through the air, causes the string of a piano-forte to sound. The impression of light is motion itself. But this motion, in itself, produces no change in the form and composition of the eye or of the brain, unless new causes are added, and to such new causes belongs the act of thought, by which the impression becomes a felt sensation, which arouses ideas and images.

No one, probably, would seriously maintain, that a sheet of white paper, or the light reflected from it, produces a change in the form and composition of the brain, for in this case, a sheet of black paper, which reflects no light, would necessarily produce an effect, although an opposite one. But the same white and black, in the form of letters in a book, excite the most manifold sensations, ideas, and images, and, by means of these, and not by means of the light, exert an influence on the composition of the brain.

Sound, as a stimulus.

The case is exactly the same with sound. The vibration of the aerial waves is propagated through the external auditory organs, and communicated to the auditory nerves. The motion of the tympanum alters neither its form nor composition, any more than the form and composition of the particles which form it receive a similar motion. The eye is fatigued in a gallery of paintings, although it receives far less light than in the open air; and so it is with sound.

Erroneous notion of reaction.

False notions, which are gradually incorporated in a word, are always the causes of constantly recurring

misunderstanding, or of the impossibility of our understanding one another. This is the case, for example, with the word reaction, which means opposite action, but is used in physiology in quite a different sense. It is said that the gland reacts against the irritation, when its power of secretion is increased by an external cause, as is shown by the increased amount of secretion when the stimulus is applied. It is said to be a property of the living body, that the augmented activity of the gland does not continue, even if the stimulus be continued, although it is in the nature of the thing that the secretion must cease, when no matter capable of secretion is left, and that it begins again as soon as a new supply is furnished. The action of the stimulus is here not action on the gland, but on the cause which regulates the secretion, so that the gland, in consequence of the stimulus, secretes more at one time than at another.

So there goes on, at every moment, in the tail of a lizard, a metamorphosis and renewal of its particles, and when the tail is cut off, and thus the continuity of the cut surfaces is broken, the forces which produced that continuity, acted in opposition to the solution of continuity by the knife, but a reaction of the vital power against the knife does not take place. The cut surface of the severed tail does not renew itself, but the other cut surface, which is in connection with the organism, does so, not in consequence of a reaction, but because the causes of its renewal continue to operate unceasingly. The body of the lizard cannot restore itself, if food be not supplied. In this case, when the tail has grown again, other parts have lost weight in the same proportion. The organic body behaves, in all its relations, like other bodies. A number of effects, produced in it by external causes, are permanent, even when the cause which produces them does not continue in operation; others are balanced, when a permanent cause of disturbance is wanting, because in the body, forces, or causes of resistance are in activity which operate uninterruptedly.

Verbal explanations are no real progress.

The trifling progress made in the mechanical period of physiology sufficiently shows, that the most ingenious description of the function of an organized body, as, for example, of respiration, of digestion, or of a morbid state, does not suffice to attain a knowledge of it; and that the most

acute combinations contribute nothing to our progress, unless they are founded on a more accurate and precise determination of the facts actually existing, or on the observation of new facts. The imagination alone does not enable us to quit our original position, and a mere series of views and opinions cannot be called an advance, but may be compared to the proceeding of a man, who turning round in a circle, tries to obtain a multiplicity of points of view. These points of view, indeed, are necessary, because by them we learn the direction in which we must apply our force; but the description of a state or condition, as, for example, of that of a catarrh, an inflammation of the mucous membrane of the nose, can never be regarded as an explanation, nor as the final object of an investigation. A new expression for a cold, as *an injurious influence operating on the cutaneous nerves*, is no real, but only an apparent gain.

Exercise of the perceptive powers is a necessary condition for observation.

The right use of our senses, the appreciation of a distance, or of the height or circumference of an object, is acquired by experience and reflection. In like manner, the right comprehension of a natural phenomenon, and the true and simple description of it, unmixed with the notions excited in us by its perception, are attributes only of a well-practised and experienced intellect. The botanist recognizes by a mere glance, the presence, or the peculiarities of the individual plants which surround him; the eye of the artist takes in a number of individual facts, which the unpractised eye, in many cases, is unable, even with effort, to perceive. In no one of all the experimental sciences is this sharpening and exercise of the perceptive powers more necessary and more profitable than in Physiology and Pathology; in none of them is truth more rarely attained than in Medicine. Hence the numerous contradictions in the understanding of the simplest facts; hence the succession of the most opposite modes of cure, the appearance of a multitude of works, which again vanish without leaving a trace of their existence, on the unhealthiness of a district, on the nature of yellow fever, of plague, of cholera, written by persons to whom the localities of the unhealthy district are totally unknown, and who never had an opportunity of seeing a patient in yellow fever, plague, or cholera. In order to obtain acceptance for a theoretical view in Chemistry

or Physics, it is indispensably necessary that he who proposes it should have furnished, by previous practical investigations, a sufficient security for his possessing the powers of perception and combination. If this security be wanting, his opinion is left unnoticed, even when it is an expression fully corresponding to the truth; and, in like manner, contradiction or opposition to received views on the part of a mere theorist, does not excite the slightest attention. It required a Berzelius, with his acute perceptive powers, to save from oblivion the notions of Richter concerning chemical proportions, to recognize their interior truth and the existence of a universal law of combination under a mass of false facts, of which a single example—that of the carbonate of alumina, employed as the starting-point of the first table of equivalents, *which salt does not exist*, was sufficient to destroy all belief in the more accurate remaining facts.

Error depends on fallacious observations and combinations.

From the point of view of true natural philosophy every erroneous mode of contemplation and interpretation depends on the want of correct observations and on the false notion entertained of the nature of an observation. It further depends on this, that we regard the constant association of two things, or the constant occurrence, simultaneously, of two phenomena, as a necessary connection, and consider them as mutually determining one another. In nature, a number of phenomena appear together, one of which is not perceived when the other is wanting, but there are numberless others which occur together, without the remotest connection. The supposition of a relation thus fallacious, or a false *nexus causalis* proceeds in all cases from a false method of observation. So, also, the association of two phenomena, which are only analogous in one solitary relation, is always the result of imperfect observation.

Observation.

To see, to perceive by means of our senses, is one condition of observing; but seeing and perception do not characterize true observation.

The problem to be solved by the observer, is, not merely to see the thing, but also the parts of which it consists. A good observer must notice and seek to convince himself, in what connection the parts stand to each other and to the whole.

Examples of erroneous observations. Influence of the moon on the formation of dew.

One of the best-known examples of fallacious observation, is that of the influence ascribed to the moon in the cold of moonlight nights, on the formation of dew and hoar frosts; whereas the moon is a mere spectator, while dew and hoar frost are formed.

In a lecture, in other respects an excellent one, which was delivered last year in Dresden, the following passage occurs:—

Of the atmosphere on evaporation.

"Without an atmosphere we cannot imagine even the existence of water, or a similar fluid in the liquid form. If our earth could be suddenly stripped of its atmosphere, its rivers and seas must evaporate, and the whole earth would soon dry up, just as we see in performing the experiment on a small scale with the air-pump."

Here we perceive that a connection is supposed and assumed between evaporation and the atmosphere, which does not exist in nature. Without the atmosphere no clouds would be formed; water would not be supported in the form of vesicular vapor, and its vapor would not rise to so great a height; but on evaporation the atmosphere has no influence; and, under the receiver of the air-pump, an equal quantity of vapor is formed, no matter whether it be full of air or exhausted.

Dilution of the oxygen in the atmosphere by the nitrogen.

In how many physiological works has the opinion been expressed that the nitrogen of the atmosphere serves to dilute the oxygen, to retard and moderate its action on the organism, while the amount of oxygen in a given space would not be altered, if we suppose the nitrogen removed.*

* *Note by the Editor.*—I am not aware that in this country, the above erroneous view is attached to the expression, that the nitrogen of the atmosphere serves to dilute the oxygen. It is only meant that such an atmosphere as ours, containing one-fifth of its volume of oxygen, diffused through the whole space, is less active in supporting combustion, and in exciting the animal system, than an atmosphere of oxygen would be, such an atmosphere as would exist, if the nitrogen were not only *removed*, but *replaced* by an equal volume of oxygen. It is no doubt true, that if the nitrogen were removed, without being replaced, the oxygen would still occupy the same bulk as it does now, and although pure, would not be less diluted than before; but this is not what is meant; for in that case, the atmosphere would be reduced to one-fifth of its present weight and pressure. I conceive that, in the sense here explained, the nitrogen may be accurately said to dilute the oxygen, although it does not remove the particles of that gas farther asunder. It dimin-

Two gases, of different nature, exert, on the human body, or on that on which they rest, a certain pressure; but the particles of one gas do not compress those of the other. If we bring into communication by a tube two bottles, one of which contains nitrogen, while the other is empty, the nitrogen diffuses itself through both bottles. If their size is the same, one bottle now contains as much nitrogen as the other. The same thing occurs, if one bottle, instead of being empty, is full of oxygen under the same pressure; the nitrogen diffuses itself through the oxygen, as if no oxygen were present, and the oxygen behaves in like manner with reference to the nitrogen.

The power of the sun's rays in attracting water.

The observation that many mines cannot be wrought in the height of summer, on account of the water with which the galleries become filled, has induced many philosophers to ascribe to the sun's rays a power of attracting water, which, as they say, is naturally explained by the fact that, by the sun's action, the soil is dried up, and vacant spaces arise, which by capillary attraction are again filled up with water from below. Now we know that a connection does exist between the sun and the water of the mines; which, however, is simply this, that in summer the brooks dry up by which the pumps are driven, intended to remove the daily supply of water, as fast as it flows in.

The relation between spirit drinking and spontaneous combustion, may be somewhat similar, since it is only drunken persons who are apt to fall into the fire and thus be consumed.

Origin of the alkalies in plants, according to Boerhaave.

The false notion of living and dead, or vital and dead forces, which at the present moment separates the province of chemistry from that of physiology as an unfathomable abyss, rests merely on the want of just, and the existence of erroneous observations. These views are like those which were held even in the eighteenth century, in regard to the occurrence of alkalies in plants; and which are still retained in pathology in reference to the growth of a crystal and the nutrition of an organic being. The alkali belonged neither to the juice nor to the plant; it was a product of the combustion. Boerhaave told

ishes the activity of oxygen, by excluding its own volume of that gas, which would be required to yield an atmosphere of nearly the same density as ours, if substituted for the nitrogen.—W. G.

his hearers that rotten wood gives no alkali, and that the alkalies were as little parts of the plant as the glass which some plants yield when burned.

Fallacious comparison of the cohesive force in crystallization with the organic or vital force.

"For crystals, as well as for cells," says Henle (Rationelle Pathologie, Part I., p. 101), "there is, even under the most favorable circumstances, a maximum of growth, although in the former it varies between wider limits than in the latter. Crystals, like cells, arrange themselves to form aggregates, which even remind us of the arrangement of the particles in the higher vegetables by their usually arborescent forms. Dead and living bodies oppose to external influences a certain appreciable resistance, accommodate themselves to circumstances, or lose their form. The most significant analogy between crystals and individuals of the organized world, is seen in the behavior of both after injuries from external causes. Crystals, like organic bodies, have the power of restoring lost parts more or less perfectly. There, as well as here, the power which formed the bodies continues to operate in them when formed, independent of the substance, the loss of which they survive and replace. If a mutilated crystal be placed in a liquid, from which it can attract matter of the same nature, it grows indeed as a whole, but especially and most rapidly on the side where it was mutilated, so that, above all things, the regular form is restored; just as a mutilated animal, out of its food, first of all replaces, as far as typical laws allow, the lost parts."

Although it be true, that in the organic body, increase of mass is effected by a force of attraction, yet even in the external appearance there is no analogy between the growth of a crystal and the formation of an organism. The form of membrane is not determined by the physical form of the atoms of gelatine, as occurs in a crystal of alum, which consists of an aggregate of particles of alum, each of which has a form like that of the large crystal. A cell is complete in itself, and not an aggregate of smaller cells.

Explanation.

There is not, for crystals, as there is for cells, a limit to their growth. Their growth is not, like that of organisms, effected by a cause acting internally and externally, but by an attraction of surface. At all points of the surface this force acts; the particles under the surface take no share in the growth;

they may be removed without taking from the surface its power of growth. The new surfaces, formed by the mutilation of a crystal, exert no stronger attraction on the particles of the surrounding medium than the other surfaces: they do not grow more than the others. By breaking off the angles of an octohedron, we obtain a cubic surface of the crystal bounded by four converging surfaces of the octohedron. In the crystallizing liquid, the crystal grows in three dimensions, and in consequence of the lengthening and convergence of the surfaces the angle is restored, and this occurs, even when the cubic face is covered with varnish. If from a cube of alum one side is broken off, it increases in the mother liquid in no greater proportion on the mutilated side than on the others; the original form is not restored, because the attraction of one part of one face of the cube is not greater than that of any equal surface on any one of the remaining sides.

A crystal, suspended and growing in a saturated solution, always increases principally in one direction only, and that is on the side looking towards the bottom of the vessel, which is naturally always surrounded by the most dense and most highly saturated solution. There are cases, where, in consequence of a difference of temperature above and below, a crystal grows in the lower part, while the upper part is dissolved so as to lose its form.

Comparison of the parasitic theory with the chemical theory of contagion, miasms, and putrefactions.

The greatest errors and mistakes arise from this, that in appreciating morbid conditions, things which generally occur together are regarded as determining one another, the one as the cause of the other. Thus, for example, for the right understanding of morbid conditions and for the proper choice of remedies, there is no opinion so destitute of a scientific foundation as that which admits, that miasms and contagions are living beings, parasites, fungi, or infusoria, which are developed in the healthy body, are there propagated and multiplied, and thus increase the diseased action, and ultimately cause death.

When I attempt, in the following pages, by a series of facts, to connect certain changes in the organizm with phenomena observed in inorganic nature, I do so much less with the view of establishing a certain view of the nature and essence of contagions and miasms, and concerning fermentation and putrefaction, than in

order to direct the attention of philosophers to a universal cause, hitherto little noticed, which operates everywhere, when a change of form and composition, or when combination and decomposition take place. And when I shall have proved that this cause exerts a very definite and traceable influence on the manifestation and direction of cohesion and affinity, then its undeniable share in the operations of the organizm, will be so much the less liable to be questioned, that the vital force belongs to the same class as the chemical forces, inasmuch as it only acts when the particles are in contact, or at infinitely small distances.

A glance at the foundations of the parasitic theory, and of the other, which is called the chemical, will perhaps suffice to determine the value of both.

Influence of mechanical motion on the crystallization of water,

Every one knows that water is solid at all temperatures under 32°, and that during its freezing the temperature remains at 32°; and yet water may be cooled to 5° without freezing, if kept quite still. The slightest agitation, however, suffices to cause it to solidify.

on crystallizing saline solutions,

Many solutions, saturated while hot, act in the same way. When cooled in perfect stillness, they deposit no crystals; no separation of the water from the dissolved salt takes place. But the slightest motion, a speck of dust, a grain of sand thrown into the liquid, causes the part set in motion to crystallize, and when once begun, the crystallization spreads through the whole mass.

on cinnabar, iron, and iodide of mercury.

By continued agitation and trituration the black amorphous sulphuret of mercury becomes red crystalline cinnabar: hammered iron, the particles of which are promiscuously arranged, becomes crystalline by hammering. The lemon yellow periodide of mercury, when one part is rubbed, assumes a new crystalline form and becomes scarlet.

From these facts it appears that a mechanical motion exerts an influence on the power which determines the state of a body: this motion is propagated to the molecules of the bodies: to form crystals they must turn to one another certain sides or ends, in which their attraction is strongest. It is clear that in liquids as well as in solids, the atoms may be set in motion by a blow or shock, by friction, or in general by mechanical causes.

But it is not only the manifestation of cohesion on which these causes exert a certain influence; they affect also chemical affinity.

Influence of mechanical motion on the manifestation of chemical affinity.

In a diluted solution of chloride of potassium tartaric acid causes no precipitate; but mere agitation, rubbing the inner side of the glass with a glass rod, causes the instantaneous deposition of crystals of cream of tartar. Fulminates of silver and of mercury, explode violently by a blow or gentle friction; so do the fulminating silver of Berthollet, nitropicrate of lead, and other bodies. It is clear that, in these cases, the blow, the friction, or motion in general has been communicated to the atoms of these bodies; that the direction of their attraction has thus been altered. They now attract each other in new directions, and in consequence new products are formed. Fulminate of silver contains the elements of cyanic acid. By the friction or percussion, a new arrangement of these elements is brought about; a part of the carbon is given off in combination with the whole of the oxygen, as carbonic acid; along with this carbonic acid nitrogen gas is set free, and this sudden conversion of matter into the gaseous form is the cause of the explosion.

When the colorless and highly fluid body, Styrole, is placed in a glass tube, which, by a mechanical arrangement, is kept for thirty hours in longitudinal vibrations, it passes almost entirely into the solid state (Sullivan).

Heat is like the action of a mechanical force.

By heat, a number of substances are decomposed, and in these cases, its action is entirely analogous to that of a mechanical force. Heat acts like a wedge, which is forced between the atoms. If, between two atoms, the resistance which the chemical force offers to the penetration of the wedge, is less than the force tending to separate them, then they separate; decomposition ensues. Thus oxide of mercury is resolved by heat into oxygen gas and metallic mercury. In bodies which contain more than two elements, heat acts in exactly the same way. At a certain temperature the fulminates of silver and mercury explode, as do Berthollet's fulminating silver, nitropicrate of lead, &c. Heat destroys the original arrangement of the atoms, and consequently the equilibrium of their mutual attraction; they now arrange themselves in new directions, in which

their mutual attractions are stronger. The formation of new products depends on the production of a new state of equilibrium; when exposed to the same temperature, these products undergo no further change; but if the temperature be raised, a new disturbance takes place, and in consequence of this a new state of equilibrium, a new arrangement of the molecules. Thus, under the influence of a low red heat, acetic acid is resolved into carbonic acid and acetone. Here the carbonic acid contains two-thirds of the oxygen, and the acetone all the hydrogen, of the acetic acid. At a higher temperature the acetone is resolved into a compound of carbon, containing all the oxygen, and an oily carbo-hydrogen.

At a temperature of 392°, fluid styrole becomes solid, hard, and glassy (Hofmann and Blyth).

It has been observed, that platinum does not decompose nitric acid, that it is neither oxidized nor dissolved by that acid. But an alloy of platinum with silver readily dissolves in nitric acid.

Influence of the state of chemical action on the power of bodies to enter into combinations,

Metallic copper does not decompose water, when boiled with dilute sulphuric acid; but certain alloys of zinc, nickel, and copper, readily dissolve, with disengagement of hydrogen, in dilute sulphuric acid. There are alloys of these three metals in certain proportions, which are not dissolved by dilute sulphuric acid; but if, in this case, a trace of nitric acid be added to the sulphuric, an oxidation begins, which, when once begun, is continued without any further assistance from the nitric acid. The solution of the platinum and of the copper, in these experiments, takes place in opposition to electrical laws; while heat and other influences capable of exalting the affinity, have no share in the process.

or to suffer decomposition.

Again, if we place peroxide of hydrogen in contact with superoxide of lead, or oxide of silver, the decomposition of the first-named substance is accelerated as by contact with many solid bodies; but the molecules of the two oxides, in contact with the decomposing molecules of the peroxide of hydrogen, suffer an analogous decomposition; the oxide of silver being resolved into oxygen gas and metal; the superoxide of lead into oxygen gas and protoxide of lead. These two metallic oxides

behave, under these circumstances, exactly as if they were exposed to a low red heat.

It follows from these phenomena, that the state or condition of formation (combination) or decomposition of a body, the state of change of place, or motion, in which its particles are, exerts an influence on the particles of many other compounds, if in contact with them: the latter are brought into the same state; their elements are separated and newly arranged in a similar way, and acquire the power of entering into combination, a power which they did not, under similar circumstances, previously possess. The decomposition of the second body, of course, presupposes, that the resistance, offered by the forces which strive to retain its atoms in their original arrangement, is less than the force acting on them.

Inorganic bodies.

The property possessed by a substance, the particles of which are in a state of actually combining together, or of being separated by decomposition:—the property, possessed by the particles of such a substance, of producing, in other bodies of like or unlike nature, when in contact with them, the same state of change in form and composition, belongs to organic bodies in a still higher degree than to inorganic ones.

Rotten wood.

Rotten wood, in contact with fresh wood, gradually converts, under the same conditions, the fresh wood into rotten wood.

Behavior of the urea and hippuric acid in urine.

In fresh urine, if oxygen be entirely excluded, there occurs no alteration of the urea or of the hippuric acid contained in it; but if exposed to the air, another substance present in the urine undergoes a change of form and composition, which is transferred or communicated to the urea and the hippuric acid: the urea is resolved into carbonic acid and ammonia: the hippuric acid disappears, and in its place is found benzoic acid.

Influence of decaying wood on the oxidation of hydrogen gas.

Decayed wood absorbs from the air oxygen, and returns to the air an equal volume of carbonic acid. If hydrogen gas be added to the air, then the added hydrogen is oxidized along with the decaying wood; it has acquired the power of uniting with the oxygen of the air at common temperatures; a power of which, under ordinary circumstances,

it is entirely destitute. Under the same circumstances, that is, in contact with decaying wood, the vapor of alcohol combines with oxygen, and is converted into acetic acid.

Blood-fibrine and yeast act alike on peroxide of hydrogen.

Fresh blood-fibrine acts on the air like moist wood; it passes into a state of decay. If, while in this state of decomposition, it be placed in contact with peroxide of hydrogen, the latter is instantly resolved, with effervescence, into water and oxygen gas. If the fibrine be heated with water to the boiling point, this power of accelerating decomposition is entirely lost. Yeast of beer acts in the same way: it instantly produces, in peroxide of hydrogen, a separation of the elements of that compound; but if previously heated to 212°, the yeast loses this power (Schlossberger).

Behavior of complex organic atoms.

The properties just described are found in a peculiarly high degree in the complex organic atoms. In fact, the larger the number of single elements and atoms which have united to form a group of atoms of definite properties, the more multifarious the directions of their attractions, the smaller must be the force of attraction between any given two or three of the atoms. They oppose to the causes of change in form or composition acting on them, such as heat or chemical affinity, a far less resistance, they are far more easily altered and decomposed, than substances of a less complex composition.

Putrefaction.

The sulphurized and nitrogenized constituents of plants and animals are among the most complex organic atoms. From the instant that they, after being separated from the organism, come in contact with the air, they pass into a state of decomposition, which, when once commenced, continues, even if the air be now excluded. The colorless, fresh-cut surfaces of a potato, of a turnip, or of an apple, when exposed to the air, soon become brown. In all such substances, the presence of a certain quantity of water, by which the molecules are enabled to move freely on one another, is a condition necessary to the production, by temporary contact with air, of a change in form and composition, a resolving of the original body into new products, which continues uninterruptedly till no part of the original compound is left. This process has been distinguished by the name of *putrefaction*.

Further, experience shows, that a number of substances, in contact with bodies actually in that state of decomposition, that is, with putrefying sulphurized and nitrogenized compounds, are changed in a similar way: they are resolved, like the former, into new products, and their elements group themselves into new compounds, into the composition of which, for the most part, none of the elements of the putrefying body, which has acted as an excitant or ferment, enter. From all these phenomena, it is clear that the decomposition of the second body is not brought about by the exercise of affinity, on the part of the first, just because the notion of affinity cannot be separated from that of combination.

In contact with the nitrogenized constituent of germinating barley (malt), asparagine is resolved into succinic acid and ammonia: in contact with the nitrogenized constituent of sweet almonds, amygdaline is resolved into hydrocyanic acid, oil of bitter almonds and sugar, and the bitter salicine into saligenine and sugar.

Conversion of starch into sugar.

Potatoes, and the flour or meal of the different cereals, contain no sugar. Mere contact with water is sufficient to effect the conversion of the starch into sugar, in consequence of the change thus produced in the sulphurized and nitrogenized constituents.

Effects produced by animal membrane.

Animal membrane, moistened with water, effects the transformation of sugar, of milk, and of grape sugar into lactic acid; and the same property is possessed by the gluten of the cereals, by animal caseine (cheese), and by infusion of malt.

Fermentation and fermentescibility.

The property possessed by an organic body, when placed in contact with a putrefying substance, of passing into the same state of decomposition, is called, as is well known, the *capacity of fermentation*, or the body is said to be *fermentescible:* the process itself is called *fermentation.*

Different stages of putrefaction: their influence on fermentation.

If, now, it be true, that the change in form and composition of the fermenting body depends on the change in form and composition which occurs in the putrefying substance or ferment; if the new arrangement of the atoms of the one body be determined by the direction in which the particles of the other are arranging themselves; if, therefore, the fermenting body behaves as if it were a part or

a constituent of the ferment, it is evident that the mode of decomposition in the one, the way in which it is resolved into new products, must vary with the mode of decomposition of the other. In other words, the fermenting body must yield different products, when the mode of decomposition or the chemical state of motion, in the ferment, is changed.

Innumerable observations have established the accuracy of this conclusion.

Almond emulsion and sugar.

Thus, when emulsion of almonds, which, while fresh, has no action on sugar, is left to itself for a time, it loses entirely its power of acting on amygdaline. If in this state, sugar be added to it, the sugar begins to ferment, and is resolved into alcohol and carbonic acid. If the emulsion is left to itself for a longer period, it now causes the transformation of sugar into lactic acid. Infusion of malt acquires precisely similar properties. When fresh it converts starch into sugar: after eight days it loses this property, but it now causes sugar to ferment.

Caseine and sugar.

In the first period of its putrefaction, the caseine of milk effects the transformation of sugar of milk and of grape sugar into lactic acid; in a higher temperature it converts grape sugar into alcohol and carbonic acid; and when, by the addition of an alkaline base, the formation of free acid is prevented, caseine, in the last stage of its changes, causes the atom of sugar to be resolved into carbonic acid, butyric acid, and hydrogen gas.

Animal membrane and sugar.

Animal membrane behaves in a manner precisely analogous. At first it effects the transformation of starch into sugar, next, that of sugar into lactic acid, and afterwards the conversion of sugar into carbonic acid and alcohol.

Influence of a high temperature on fermentation.

The same sugar, which, in the juice of the beet-root, when fermented at ordinary temperatures, is resolved into alcohol and carbonic acid, yields, when the temperature of the juice is raised, without any thing being added to it, mannite, lactic acid, gum, carbonic acid, and hydrogen gas.

Sugar and oil of potato spirit.

The same sugar further yields, when the conditions of its fermentation are again changed, butyric acid; and in the fermenting molasses of beet-root sugar,

the same sugar is again resolved into water, carbonic acid, and hydrated oxide of amyle (oil of potato spirit, or Fuseloel, *German.*)

The transformation of sugar is like that of acetic acid in a high temperature.

Sugar of milk and grage sugar contain the same elements, and in the same proportions by weight, as lactic acid. The products formed during the fermentation of grape sugar contain exactly the elements of the atom or molecule of grape sugar. Hence its decomposition or transformation is a simple splitting up, as it were, or a new arrangement of its atoms, just as happens with those of acetic acid in a high temperature. The carbonic acid contains two-thirds of the oxygen, and the alcohol all the hydrogen, of the molecule of sugar.

The power of exciting fermentation belongs to all very complex organic atoms.

When we reflect that the power of exciting putrefaction or fermentation belongs to bodies of the most different composition, that blood, flesh, cheese, membranes, cells, saliva, infusion of malt, emulsion of almonds, &c. acquire this property, as soon as, by the chemical action of oxygen, a disturbance of the state of equilibrium in the attraction of their elements has taken place, every doubt as to the true cause, by which all these phenomena are determined, seems to disappear.

Causes of change of form and composition in matter.

The change of place or of relative position in the smallest particles of a number of complex substances, their falling asunder or re-arrangement, so as to yield new products, may be accomplished by chemical action, by heat, by electricity; but it may also be brought about by the communication or transmission of a state of motion, or, in other words, by contact with a body, the particles of which are in the state or act of changing their relative position, and consequently in a state of motion.

Propagation of decomposition once commenced.

When, by any external cause, for example, by contact with oxygen, the equilibrium among the attractions of the elements of one of these complex atoms is disturbed, the consequence is the establishment of a new equilibrium, permanent under the given conditions. The motion excited in the first particle is propagated, by contact, to the second, third, &c., similar particle, and it is also propagated to all dissimilar particles, to all other substances, when the forces which retain

their elements in their original form and composition are less powerful than the action or motion which tends to change these. Want of power to persist in the original arrangement, is want of resistance. Every body which is capable of augmenting this resistance, impedes putrefaction and fermentation, generally by entering into a chemical combination with the putrescible or fermentescible body. The power of persistance in the original arrangement is strengthened by every new attraction which is added. To the force, which determined the permanence of the one body, there is added, in the second body, with which it combines, a new attraction, which must be overcome, if the elements of the first are to undergo a change of place or of arrangement.

Antiseptic substances.

Among those bodies which arrest or prevent putrefaction and fermentation, we must reckon, above all, sulphurous acid, arsenious acid, the mineral acids, many metallic salts, empyreumatic substances, volatile oils, alcohol, and common salt. These substances exert on putrefying bodies a very unequal influence. Alcohol and common salt, in certain proportions check all putrefaction, and consequently all processes of fermentation; because by their means the putrefying body is deprived of a chief condition of its decomposition, namely, the presence of a certain quantity of water. Sulphurous acid, which is capable of combining with all organic bodies, and consequently with all putrescible and fermentescible substances, in this way prevents the transformation.

Action of arsenious acid on membranes.

Arsenious acid does not exert the slightest influence on the fermentation of sugar in vegetable juices, or on the action of yeast on sugar (Schlossberger). Even the putrefaction of blood is not checked by it; but its action on membranes and membraneous tissues is undoubted. While a bladder or a bit of skin, covered with water, in about six weeks is found thoroughly decomposed and converted into a liquid mass, the process being marked by the most horrible fetor, a similar bit of bladder or skin in contact with water containing arsenious acid, remains unchanged and devoid of smell. The cause of this difference is that the gelatinous tissues form with arsenious acid a combination which has properties similar to those of the compound of tannic acid with skin, that is, of leather.

By the recognition of the cause of the origin and propagation of putrefaction in complex organic atoms, the question of the nature of many contagions and miasms is rendered capable of a simple solution, and is reduced to the following.

Propagation of processes of putrefaction or fermentation in the living body.

Do facts exist, which prove that the state of transformation or putrefaction of a substance is propagated likewise to any parts or constituents of the living body; that by contact with the putrefying body, a state is induced in these parts, like that in which the particles of the putrefying body themselves are? This question must be answered decidedly in the affirmative.

Facts.

It is a fact, that subjects in anatomical theatres frequently pass into a state of decomposition, which is communicated to the blood in the living body. The slightest wound with instruments used in dissection excites a state which is often dangerous or even fatal.

The fact, observed by Magendie, that putrefying blood, brain, bile, eggs, &c., laid on recent wounds, cause vomiting, lassitude, and death after a longer or shorter interval, has never, as yet, been contradicted.

It is a fact, that the use of several kinds of food, as flesh, ham, sausages, in certain states of decomposition, is followed in healthy persons by the most dangerous symptoms, and even by death.

Products of disease: what is meant by that term.

These facts prove, that an animal substance in a state of decomposition, can excite a diseased action in the bodies of healthy persons; that their state is communicable to all parts or constituents of the living body. Now since, by products of disease we can understand nothing else than parts or constituents of the living body, which are in a state of change in form or composition, it is clear, that by means of such matters, as long as this state continues, as long as the decomposition has not completed itself, the disease will be capable of being transferred to a second or third individual.

Antiseptics prevent the propagation of contagions and miasms.

Moreover, if we consider that all those substances or causes, which destroy the communicability of contagions or miasms, are at the same time effectual in checking all processes of putrefaction or fermentation; if daily experience shows, that, under the influence of em-

pyreumatic substances (of wood vinegar, or pyroligneous acid, for example), which most powerfully oppose putrefaction, diseased action in malignant ulcerated surfaces is totally changed; if, in a number of contagious diseases, for example, in typhus, an almost never-failing product of putrefaction, namely, ammonia, free or combined, is observed in the air, in the urine, in the fæces (as phosphate of magnesia and ammonia), it appears impossible to entertain any doubt whatever as to the origin and propagation of many contagious diseases.

The putrefactive process, as a cause of contagious diseases.

Lastly, it is a universal observation, that "the origin of epidemic diseases is often to be traced to the putrefaction of large quantities of animal and vegetable matters; that miasmatic diseases are endemic in places where the decomposition of organic matter is constantly taking place, as in marshy and moist localities; that they are developed epidemically under the same circumstances after inundations; also in places where a large number of people are crowded together with insufficient ventilation, as in ships, prisons, and besieged places." (Henle, Untersuchungen, p. 54.) Again, p. 57; "But we can never so surely predict the rising of epidemic diseases, as when a marshy furface has been dried up by continued heat; or when extensive inundations are followed by intense heat."

Hence, according to all the rules of scientific investigation, the conclusion is fully justified, that, in all cases where a process of putrefaction precedes the occurrence of a disease, or where the disease can be propagated by solid, liquid, or aeriform products of disease, and where no nearer cause of the disease can be discovered, the substances in a state of decomposition or transformation must be regarded as being, in consequence of that state, the proximate causes of the disease.

Liability to contagion: on what it depends.

The condition which determines, in a second individual, his liability to the contagion, is the presence, in his body, of a substance, which, by itself, or by means of the vital force acting in the organism, offers no resistance to the cause of change in form and composition operating on it. If this substance be a necessary constituent of the body, then the disease must be communicable to all persons; if it be an accidental constituent, then only those persons will be attacked by the dis-

ease, in whom it is present in the proper quantity, and of the proper composition. The course of the disease is the destruction and removal of this substance; it is the establishment of an equilibrium between the cause acting in the organism, which determines the normal performance of its functions, and a foreign power, by whose influence these functions are altered.

The author calls on physicians to test his views.

Practical Medicine will soon decide whether this view is just, or whether it must be rejected: we shall see whether actual relations exist between the action of arsenious acid on animal membranes out of the body, and its effect in certain fevers; between the action of mercurial preparations on animal matters out of the body, and their effects in contagious diseases. If what is called the chemical view, by a careful study of the putrefactive processes in single and mixed substances, and of all matters or causes which change, impede, or accelerate them, as well as by comparing them with analogous processes in the organism, do not become to the physician a guide and leader, by whose means he may acquire the possession of new facts: if what is thus gained be not capable of exalting his insight into the diseased processes; if the choice of means, to avoid and remove these morbid actions, do not in this way acquire a firmer foundation than it possesses at this moment:—then it is not worth while to uphold it. The chief obstacle to the adoption of this view is its simplicity. While every physician or physiologist admits inferior food, want of fresh air, the continued use of salted meat, &c., as causes of the most surprising changes in the vital process; while no one hesitates to regard a slight change of temperature, in many cases hardly to be detected by the thermometer, as a cause of inflammation, fever, and death, all influence on the organic vital process is denied to one of the most powerful causes of changes in form and composition in organic bodies. Men refuse even to test a view, which is founded on a firmly linked concatenation of a large number of the most obvious facts, although against this view there is nothing but its easy comprehensibility. But it is this very character which distinguishes the results of the physical mode of investigation. Although every pathologist and physiologist is fully convinced, that, without calling in the help of the chemical and physical forces, no organic process can be explained, yet,

hitherto, every explanation in which a part has been allotted to the chemical and physical forces has had the fate of being doubted and rejected by physicians.*

If we compare what is called the chemical theory of contagion with the parasitic theory, it is hardly possible to understand how men of intellect, philosophers of the highest order, could favor or defend a theory, which the experience of every day contradicts.

Parasitic theory.

The foundation of the parasitic theory may be referred to two facts: one is the mode of propagation of scabies; the other is a disease occurring in silkworms, the muscardine.

Scabies.

Scabies is an inflammation of the skin, excited by the irritation of a kind of mite (*Acarus scabiei, Sarcoptes humanus*), which lives in the skin, or more accurately speaking, in its passages or pores. For the communication of scabies there is required a long-continued approach or contact, especially at night, because the acarus is a nocturnal animal of prey. That the animal is really the contagion of this disease is proved by the following facts. *a.* Inoculation with the matter of the pustules does not produce scabies; nor does the placing of the crusts of the pustules on the arm do so. *b.* Scabies is cured by rubbing down the animal with brick dust, and it cannot be communicated by the male, but only by the impregnated female acarus. It becomes general over the body by the propagation of the animal, which may go on *ad infinitum.* The disease is chronic, and is not spontaneously cured. (Henle.)

Scabies is propagated by an animal.

The contagion of scabies is consequently an animal furnished with organs for taking food, which lays eggs; it is called a fixed contagion, because it cannot fly, and its eggs are not conveyed by the wind.

* An opinion concerning the action of remedies, obtained from the chemical point of view, reminded a physician in Hanover, otherwise a sagacious man, of the following anecdote. (Physiologie und Chemie in ihrer gegenseitigen Stellung, von Dr. Kohlrausch. Göttingen, 1841, p. 117.) "This classification reminded me of another, which a miner is said to have made of his superiors. There are, said he, the gentlemen of the pen, the gentlemen of the apron, and the chemists. The gentlemen of the pen understand it, but cannot do it; the gentlemen of the apron do it, but do not understand it; the chemists do not understand it, and they cannot do it."

If it be proved that scabies is propagated by an animal, then it requires neither a chemical nor any other theory to explain the communication of the disease; and it is quite obvious that all states similar to scabies belong to the same class, if by observation, the same or similar causes of communication and propagation are shown to exist.

Contagious diseases which are not propagated by animals.

If, now, we inquire what results the search after the same or similar causes in other contagious diseases has yielded, we obtain for answer, that in the contagion of small-pox, of plague, of syphilis, of scarlet fever, of measles, of typus, of yellow fever, of dysentery, of gangrene, of hydrophobia, *the most conscientious observation has not been able to detect animals or even organized beings at all, to which the power of propagation could be ascribed.*

Parasites in the body of the higher classes of animals.

On the other hand it has been observed, that a number of insects are developed and propagated only under the skin of higher animals, and that by their means, in many cases, the disease and death of the higher animal is produced. It is perfectly evident that the scabies belongs to this class of diseases, since the greater or less size of the animal can make no difference in the explanation.

There are, therefore, diseases, which are caused by animals, by parasites, which are developed in the bodies of other animals, and live at the expense of the constituents of these bodies. These cannot be confounded with other diseases, in which such causes are entirely wanting, whatever resemblance they may exhibit in the apparent phenomena. It is possible, that in the case of one or another contagious disease, further researches may furnish proof, that they belong to the class of diseases caused by parasites; but so long as the proof is not given, they must, according to the rules of scientific investigation, continue to be excluded from that class. The problem to be solved by science, in these diseases, is to discover the causes which produce them; and the mere inquiry after these causes leads to the path, by following which we shall find them.

The opinion, that infection in contagious diseases is caused by living beings, and that scabies is to be regarded as the type of contagious diseases, has been chiefly founded on the principle,

that like effects imply like causes. (Henle, Zeitschrift, ii. 305.) This is the very principle which for centuries impeded the progress of natural science, and which, even in the present day, leads to so many errors.

The purely miasmatic diseases, and what are called their miasmata, are, in regard to their origin, as well as to the mode of their propagation, as yet inaccessible to investigation; and consequently, neither the parasitic theory nor the chemical theory has attempted to explain them.

With respect to contagious miasmatic diseases, which are produced as well by a matter contained in the air, as by a matter derived from the morbid system, the parasitic theory has pointed out the muscardine as the type.

The muscardine. The muscardine is a disease of the silkworm caterpillar, which is caused by a fungus. The germs of the fungus introduced into the body of the caterpillar, grow inwards at the expense of the body of the insect; it is not till after the death of the caterpillar that they pierce the skin, and there appear on the external surface a forest of fungi, which gradually dry up and are converted into a powder, which, on the slightest motion, rises from the body on which it is spread, and is dissipated in the air. Nutritious food, perfect health and strength in the silkworms, increase the liability to infection; in a colony of silkworms the sickly caterpillars are the best. (Henle.)

Parasites in animals and plants. Similar parasites have been observed in diseased fish, in Infusoria, in birds' eggs, &c.; and it is therefore clear, that these observations establish a series of facts in the animal organizm, which are very often seen in the vegetable world, namely, disease and death caused by parasites, which live exclusively on the substances of other plants. But between these facts and the origin of contagious miasmatic diseases every kind of connection is wanting; and if it be permitted to apply to a fungus, or to the spores of a fungus, the name of contagion, then it is plain, since the greater or less size of the fungus can make no difference in the mode of viewing the question, that there are contagions six or eight inches in length; for the fungus *Sphæria Robertii*, which is developed in the body of the New Zealand caterpillar, and causes its death, attains that size.

Fallacious theory of the cause of fermentation and putrefaction.

A theory of the cause of fermentation and putrefaction, which is utterly fallacious in its fundamental principles, has hitherto furnished the chief support of the parasitic theory of contagion. The advocates of this theory regard putrefaction as a decomposition of organic beings caused by Infusoria and Fungi, and consider every putrefying body as a breeding-place for infusoria, or a nursery for fungi; and where organic bodies putrefy over a large surface, the whole atmosphere, according to this view, must be filled with the germs of these infusoria and fungi. The germs of these organized beings, are, in this theory the germs of disease, or of the causes of disease.

Fungi and infusoria do not produce putrefaction.

That a close connection exists between putrefaction, contagions, and miasms, has, as we see, not escaped the observation of the defenders of the parasitic theory. It is only in the mode of understanding the connection of these phenomena, and their mutual dependence, that the explanations differ. This connection, as understood in the parasitic theory, would be established if it were proved: that, in point of fact, infusoria or fungi produce putrefaction or fermentation; that by them, by their processes of nutrition and respiration, sugar is resolved into a volume of carbonic acid, and an equal volume of the vapor of alcohol; that, by the same means, urea can be converted into carbonate of ammonia, salicine into sugar and saligenine, protosulphate of iron into crystallized pyrites, gypsum into sulphuret of calcium, blue indigo into white indigo, starch into sugar, sugar into lactic acid, mannite, gum, oil of potato spirit, acetic acid, butyric acid and hydrogen gas, and amygdaline into oil of bitter almonds, hydrocyanic acid, and sugar.

Life is opposed to putrefaction.

The constituents of vegetable and animal tissues have been formed under the control of a cause of change in form and composition, operating in the organism. This is the vital force, which has determined the direction of attraction, and which opposes cohesion, heat, electricity, in short all the causes which, out of the body, prevented the union of the atoms to form compounds of the highest or most complex order, and annihilates their disturbing influence. In substances of so complex a nature as the organic atoms, these very forces produce changes

of form and state, when after death, their action is no longer opposed by the vital force. The same leaf, the same cluster of grapes, which possessed the property of giving out pure oxygen gas to the atmosphere, yield to the chemical action of oxygen from the moment that, after being separated from the organism, they are brought in contact with that element.

No organism, no part of an animal or plant, is capable, after the extinction of the vital action, of resisting the chemical action which air and moisture exert on them; their elements then become subject to the unlimited power of the chemical force. Fermentation and putrefaction are stages of their return to less complex combinations, and at last the elements of organic beings, in consequence of the causes uninterruptedly acting on them, again assume those original and most simple forms of combination (carbonic acid, water, and ammonia) in which they can serve for the development and support of new generations.

Fungi and infusoria are subject to putrefaction, fermentation, and decay.

Fungi and infusoria are organic beings, and their constituents are of a nature quite as complex as those of the higher plants and species. After their death, we observe, in their remains, exactly the same phenomena which accompany the disappearance of all organisms; we perceive in them putrefaction, fermentation and decay. How is it possible, then, to regard fungi and infusoria as causes of these processes, when they themselves, these supposed causes, putrefy, ferment, and decay, so that nothing is left of them but their inorganic skeleton?

They are accompaniments of the putrefactive process, not its causes.

No one can deny that fungi and infusoria are observed in a number of putrefying and decaying substances; but the frequency of their occurrence cannot possibly serve as a reason for regarding the accompaniments of certain states as the causes of those states. Fungi and infusoria are, by nature, rendered dependent, for their nutrition and development, on organic atoms which have ceased to be parts or constituents of living organisms. In most cases, they only appear, when true putrefaction has begun or is completed, and the process of decay (or slow oxidation) has set in. There can be no doubt that by their presence the processes, and consequently the products, are altered; for, in virtue of their own processes of

nutrition and respiration, they are the accelerators of the process of resolution; by their action the injurious effect of that process on surrounding objects is limited to the shortest possible time.

Since, with the reconversion of the elements of organic beings into carbonic acid and carbonate of ammonia, all putrefactive processes are at an end, it is plain that the time necessary for this purpose must be singularly shortened, when the putrefying body becomes the abode of infusoria, and millions of these animals are most industriously engaged in causing the constituents of the organic beings, by means of their respiratory and digestive processes, to be resolved into these ultimate products.

Fungi and infusoria accelerate putrefaction and decay,

The important part assigned by nature to the infusoria, which makes them the true enemies and destroyers of all contagions and miasms, can no longer be overlooked, now that the most indisputable facts have demonstrated, that the green and red infusoria, during their processes of life and propagation, are sources of the purest oxygen gas.

and thus become the adversaries of the putrefactive process.

Fungi act in a very similar way; while they consume for their support the true exciters of putrefaction, namely, the sulphurized and nitrogenized constituents of plants, they impede putrefaction, and promote the gradual conversion of these substances into the ultimate products of decay.

The opinions concerning the cause of putrefaction, which the adherents of the parasitic theory have formed, are founded chiefly on observations which have been made on the formation of yeast in the fermentation of wine and beer. But the investigation into the nature of yeast is not yet completed. It is conceivable, that to the present microscopic observations others may be added, by which all doubt as to the vegetable nature of yeast may be banished; but even were this to happen, the explanation of the conversion of sugar into alcohol and carbonic acid would not admit of any other expression than that which has been furnished by the chemical theory.

Nature of the yeast of wine and beer.

It is a fact fully proved, that, in the vinous fermentation, the elements of grape sugar are recovered in the form of alcohol and carbonic acid, without loss of weight, and those of cane sugar with an increase of

Behavior of yeast in solution of sugar, grape-juice, and infusion of malt.

weight. We cannot, therefore, suppose, according to our ordinary notions, that any of the particles of the sugar are employed in the nutritive and respiratory process of an organized being. In the fermentation of grape juice and of infusion of malt, the weight of the yeast or ferment increases; but if yeast be added to a pure solution of sugar, fermentation indeed equally takes place, but in this case the weight of the yeast, instead of increasing, diminishes. By repeatedly placing the same portion of yeast in contact with fresh portions of solution of sugar, it entirely loses, at last, its power of exciting fermentation, while its weight continually diminishes. Thus, as we perceive, one and the same effect would necessarily be ascribed on the parasitic theory, to two directly opposed causes, one of which is a capacity of increase, the other the very opposite of propagation. If we assume, that the nutritive and respiratory process of the fungus depends on a sulphurized and nitrogenized substance, containing the elements of the fungus, and that the fermentation of the sugar is an accidental phenomenon, accompanying the development of an organized being, it is still utterly incomprehensible how it happens that the fungus should not reproduce itself in a fluid where the chief condition to its propagation is present, while it immediately increases as soon as the accidental accompaniment of its vital process, namely, the sugar, is added. When, for example, in grape juice, all the sugar has been decomposed, and the air is excluded, the residue of the sulphurized and nitrogenized matter, dissolved in the juice, keeps for years without any change whatever; but if sugar be added to the liquid, the fermentation again commences and yeast is again separated. When the added sugar is decomposed, this separation of yeast ceases; but it begins again when a new portion of sugar is added, and this continues until the liquid contains an excess of sugar undecomposed.

The formation of yeast, and that of alcohol and carbonic acid from sugar, are mutually dependent.

From these facts we may obviously deduce a mutual relation of dependence, such as the chemical theory requires, between the form and composition of the sulphurized and nitrogenized body, which is converted into yeast, and the new forms and composition which are given to the atom or molecule of sugar; and it is clear that the state or condition, in which the elements of the former are during

their union to form yeast, and their resolution into other products, is the cause of the peculiar decomposition of the sugar. In no other mode of decomposition of sugar, such as its conversion into lactic acid by the action of animal membrane, or its resolution into mannite, gum, butyric acid, acetic acid, &c., have organized beings like fungi or animals been observed; nor have such organic beings ever been noticed in any other process of putrefaction or fermentation, recurring invariably in the same forms, and thus determining the nature of the products.

Vibriones in urine.

In many specimens of urine, during their putrefaction, the presence of vibriones may be detected; but in numberless other cases, when urine putrefies, it is impossible to discover in it any organized being whatever; and if, in a single case, in which fresh urine has been made to putrefy by means of the white deposit found in putrid urine—if, in only one such case, the absence of vegetable or animal organisms can be demonstrated, this one fact is quite sufficient to dissipate every doubt concerning the true cause of its putrefaction.

Fungi contain sugar.

Finally, if we reflect, that in all fungi yet examined, analysis has detected the presence of sugar, which, during their vital process, is not resolved into alcohol and carbonic acid; but that immediately after their death, from the moment that a change in their color and consistence is perceived, the vinous fermentation sets in, it is obvious that all analogy was wanting, such as could justify us in regarding the vital process of these plants as the cause of that fermentation. It is the very reverse of the vital process, to which this effect must be ascribed. (Schlossberger, Ann. der Pharm. lii. 117.)

Change of the putrefactive process in air which has been ignited.

We may consider it as established by the most beautiful experiments, that the putrefactive process in flesh and in many animal substances takes a very different form, when these substances are preserved in vessels, containing air which has been heated to redness; when, therefore, the co-operation of infusoria is excluded. But these animal substances, under such circumstances, do by no means retain their original consistence; their color and the connection of their parts are changed; and if, for example, the amount of water necessary for the complete decomposition of the flesh be present,

it sinks, after a longer or shorter time, into a putrid, fetid mass.* We have only to recall the behavior of fresh urine, in order to perceive, that for many of these animal substances a continually renewed supply of oxygen is a condition of their putrefaction; that when oxygen is excluded, urea is not converted into carbonate of ammonia; that, in close vessels, they convert into carbonic acid the oxygen of the included air, and that by the removal of this oxygen, the whole process is impeded, and is at any rate altered.

Opinion of the partisans of the parasitic theory in regard to fermentation.

The partisans of the parasitic theory assume, that by the passing contact of grape juice with the air, without which its fermentation does not begin, the germs of the yeast fungi, universally present in the air, obtain access, and that these germs, after having thus found the fertile soil necessary to their vital process, are now most luxuriantly developed. But they do not explain how it happens, that the brewer of beer must add yeast, in order to cause his worts to ferment; or how the same germs, supposing them to exist in the air, are not developed in this soil (the worts, or infusion of malt), although in it all the conditions of their life and propagation are present. They forget entirely, that the fermentation of grape juice begins with a chemical action; that an appreciable volume of oxygen is absorbed from the air; that the juice then becomes colored and turbid, and that the fermentation commences only with the appearance of this precipitate. They do not consider, that with the quantity of oxygen which is added, the fermentation diminishes, instead of increasing; that with a certain proportion of oxygen, when the substance which absorbs the oxygen has become insoluble, fermentation no longer occurs in the same juice.†

* In the beautiful experiments of De Saussure, he observed the striking fact, that hydrogen, produced by the action of iron on the vapor of water, at a red heat, when in contact with putrefying and decaying animal matters, did not combine with oxygen; while pure hydrogen, obtained at the ordinary temperature, is readily converted into water under these circumstances. In an investigation into the influences *of air which has been ignited on the putrefactive process,* this fact is well worthy of attention. It is possible that the destruction of infusoria and fungi, is not the only cause of the modification thus produced in that process.

† Two cubic centimetres of must (grape juice), 30 millimetres in diameter and 3 millimetres in depth, in contact with 20 cubic centimetres of oxygen

Until all these points have been entirely cleared up, it is contrary to all sober rules of research to regard the vital process of an animal, or of a plant, as the cause of any process of fermentation or putrefaction; and in every case, in which the presence of organic beings cannot be demonstrated by investigation in the contagion of a miasmato-contagious disease, the opinion that they have taken, or take, any share in the morbid process must be rejected as an hypothesis destitute of all support.

Two simultaneous phenomena are often regarded as cause and effect.

Another error, not less gross, in the mode of viewing phenomena, and of drawing conclusions from them, is often committed, when two phenomena, differing in manifestation, are regarded as mutually determining one another; and when the description of the one phenomenon is considered as an explanation or definition of the other. This is the case, for example, with the explanation which is given of fever, of crises, &c. Some examples of similar fallacious associations, which occur in daily life, may best serve to illustrate what is here intended.

Examples.

Nothing, for example, is more common than the belief, that storms cause a fall of the mercury in the barometer, and that, consequently, storms exert an influence on the height of the mercury in that instrument.

Storms as the cause of the unusual changes in the barometer.

Storms are effects of the disturbance, by a difference of temperature or other causes, of the equilibrium of the atmospheric pressure. A change in the pressure of the atmosphere is shown, among other things, by the falling or rising of the column of mercury, which balances a column of air of equal diameter. The two things, the storm and the height of the barometer, stand in no direct connection with one another. The storm has no influence on the height of the barometer; they are only connected through the cause which determines both. The same is the case with the erroneous notion which connects the fall of the barometer with the production of rain.

gas, did not ferment: while a similar stratum, without the addition of oxygen, produced, after exposure to air for a short time, a considerable disengagement of carbonic acid. (De Saussure, in the Journal für Chemie, lxiv. 47—51.)

The symptoms of fever must not be regarded as its causes.

The notions which many pathologists have formed concerning the cause of fever belong to this class of false views of the *causa efficiens*, and of the confounding of the notions of effect and cause.

Henle's explanation of fever.

"I am far," says Henle (Untersuchungen, p. 240), "from wishing to decide this controversy, the discussion of the question whether there be essential fevers or not; but I think I can contribute something towards enabling each party to understand better, first itself, and then its opponent. It has been found that febrile symptoms are the results of an alteration of the central organ (spinal chord). This alteration is the proximate cause of febrile symptoms, and since fever consists of these symptoms, of the complication of altered temperature, altered circulation, thirst and lassitude, this alteration of the central organ is the proximate cause of fever; or rather is fever itself."

Leaving out of view, that these three propositions are not three links in a deduction, since each of them asserts the same thing; we are bound, as long as the connection of the febrile symptoms, and the alteration of the spinal marrow, as effect and cause, is not demonstrated, to regard febrile symptoms as only signs of the changed state of that organ. To the signs of fever, which are seen externally, scientific investigation adds a new sign. The alteration of the central organ is *a fact* observable or observed by the senses; not *a cause.*

Method to be pursued in investigating the cause of fever.

Assuming that this alteration is always and invariably accompanied by febrile symptoms, the discovery of the cause of fever, or its explanation, embraces the demonstration of the connection of the three invariably returning signs of fever, namely, the subjective feeling of illness, altered circulation and respiration, and altered temperature, which characterize the febrile state, as well as the ascertaining of the relation of their mutual dependence. If we exclude from the investigation, as being hitherto, in reference to their ultimate causes, undiscoverable, the sense of illness, of cold and of heat, then we have to ascertain in what connection the alteration of the spinal chord stands to the accelerated circulation and respiration, and to the altered temperature. Before we can speak of an explanation, the idea of motion must be defined, the source of the moving power,

and of the heat of the body, must be discovered. If we now wish, according to the physical method, to investigate the cause of fever, and if we suppose, that there is produced in the heart itself, by the co-operation of several, say of two causes, a certain amount of force, by which the circulation is determined, then the motion is uniform or normal, when the number of pulsations in each second is equal, that is, when the force is divided among equal times.

Points of view in this investigation.

When the same amount of forces, in consequence of a disturbance in the relation of the two causes, which we suppose to be seated in the heart, is in one period increased, and in another diminished, then the pulsations of the heart are more rapid in the one period, slower in the other. The force produced is in this case not proportional to the time of its consumption. It is clear that on this supposition (that is, if the force is produced in the heart,) the alteration of the spinal chord can exert no other influence on the change of the phenomena of motion, on the acceleration or retardation of the heart's pulsation than that, in consequence of its state, it opposes to the motion in one period a less resistance than in the other. The causes of motion, however, are not only in the heart; they are everywhere, in every part of the organism, in the spinal chord, as well as in every single muscular fibre.

Investigation into the connection between the spinal chord and the motions of the organism.

But we may suppose, that the motion of the heart as well as that of all other parts of the organism, the motions of the intestines, and the voluntary motions, proceed from the spinal chord, or are effected by its means; and in that case it is plain that an alteration in the state or in the composition of the spinal chord must be followed by a change in all the phenomena of motion. The same thing must happen when any part of the nerves in connection with the apparatus of motion of the blood, of the intestines, &c., suffers a change in its state or composition. The alteration of the power occurrring in these parts, must influence, by a reflex action, the spinal chord and the apparatus of motion. The laws of the propagation or communication of motion, are everywhere the same, whatever may be the causes by which it is produced.

The cause of motion in a mill, of the rotatory motion of the

mill-stone, of the bolting of the flour, &c., is not the mill-wheel, for the mill-wheel is a part of the mill. It is quite certain that a want of uniformity in the working of the mill may be caused by removing from the mill-wheel several of the water-buckets, the consequence of which is, that the pressure of the water ceases to act on these parts; but it may also be effected by breaking off the cogs from any other wheel of the mill, which will always be perceptible in the circumstance, that the motion of the water-wheel is thus rendered unequal, as well as in the other parts of the mill.

Uniform and variable motions.

If, now, the organism, in a given time, produces a certain amount of force, then, as soon as this force, proceeding from the spinal chord, comes to be employed, the motions are uniform, when the force is employed in equal times for all the organs of motion; they are not uniform, when one organ receives more force than another. If, therefore, the respiration and circulation be accelerated, weakness in the limbs or disturbance in the digestive process will be the results. The excess of force which the heart receives, and by which its motion is accelerated, cannot be available at the same time for the other organs of motion.

Relation between the phenomena of temperature and those of motion in the organism.

After determining the relation between the spinal chord and the motions of the system, the next inquiry would be the relations of these motions to the phenomena of temperature in the body.

Observation teaches us, that the want of uniformity in the phenomena of motion is accompanied by a variation in those of temperature; in many cases, the subjective and objective phenomena of temperature rise and fall with the acceleration or retardation of the phenomena of motion; while in other cases, the two classes of phenomena do not appear simultaneously in the same proportion. But with the restoration of uniformity in the symptoms of temperature, the phenomena of motion also become uniform; and when the latter have become normal, the phenomena of temperature are found to be proportional to these movements. If, now, it can be shown, that the resulting motions (the velocity) does not of itself produce heat (for example, by friction), then it follows, that temperature and motion in the body are to each other in no closer relation than are the storm and the abnor-

mal height of the mercury in the barometer; and that, therefore, the causes which have determined the one series of phenomena are at the same time conditions of the other. Should it now be found, that the number of the degrees of heat liberated in a given time bears a definite proportion to the number of blood corpuscules which have passed through the capillaries in the same period, then we should have to look for the source of heat in a certain quality of the blood corpuscules, or of the blood and of the capillaries.

Relation of the phenomena of temperature to the oxygen of the air.

Since, now, it has been proved by investigation, that that quality of the blood, in virtue of which it is capable of becoming a source of heat, consists in its power of absorbing oxygen; since the absorption of oxygen in a given time bears a definite proportion to the number of respirations in that time, the unequal heating effects are dependent on the respirations, on the contractions of the heart, and also on an external cause; and this is the chemical action of oxygen. As the relative proportion of these three factors varies, so must the phenomena of temperature in like manner vary; and if, in certain parts of the organism, the capacity of entering into combination with the oxygen is increased by any new cause, then more heat will be set free in those parts than in the rest. If, therefore, the circulation and respiration are simultaneously accelerated, then, according to the beautiful law ascertained by Vierordt, the absorption of oxygen, and with it also the amount of heat set free, will also increase; if the circulation and respiration are accelerated, not in equal but in unequal proportion, then the subjective or objective sensation of heat will also vary. When all these relations shall have been investigated and ascertained, then we shall be enabled, not only to explain the individual symptoms, and consequently the nature of fever, but to refer them collectively to one ultimate cause (the cause of disease). Such is the course to be pursued in scientific investigation.

Fallacious combinations.

Erroneous combinations or connections of propositions or facts of another kind are sometimes produced by the circumstance, that in explaining a natural phenomenon, determined by several causes, we only attend to one of these causes, and attribute to it an efficacy which by itself it does not

possess, but only acquires by the co-operation of the other causes Thus, for example, according to Schleiden (Grundzüge der wis senschaftlichen Botanik, 1845, p. 282), the opinion "that fermen tation and putrefaction are effects of the communication of motion;" the notion, therefore, that a molecule of sugar, in contact with yeast, behaves as if it were a part of the yeast, "is partly founded on the untenable atomic doctrine, and partly conceived on false mechanical principles. The amount of motion is measured by the product of the mass, multiplied into the velocity. But 1 part of diastase extends its decomposing force on 1000 parts of starch" (which is an error, for, according to Guérin Varry, 1 part of diastase, acting on 60 parts of starch, only yields 10 parts of sugar. The proportion of 16 starch to 1 diastase yielded only 14 of sugar). "We must, therefore, assume in the atom of diastase, a velocity 1000 times as great as is necessary to decompose an equal weight of starch. It is easy to see that here, on the slightest foundation, a gigantic superstructure of the boldest hypotheses must be heaped one above the other, in order to reach the desired point. On the other hand, the objection that it is without example that a body at rest should set another body in motion, is also borrowed from the atomic theory, and in like manner physically false. Gravitation, magnetism, and electrical attraction, are so many examples of motion produced in one body by another which is at rest." (Schleiden.)

Rectification of Schleiden's view.

With regard to diastase and its action on starch, Schleiden has forgot to take into account the time required to effect the conversion of starch into sugar. The opinion which he combats, does not presuppose that the particles of diastase must have a greater velocity; but that the new arrangement of the starch molecule has taken place, while motion continues in the molecule of diastase, and while consequently an equilibrium has not been established in the latter. The action of diastase, in a limited time, depends on the number of starch molecules which can come in contact with the molecule of diastase, in that time. According to the quantity of diastase, the time and the process of the conversion of starch into sugar are determined. The action of the diastase ceases, when that substance has disappeared; by a double or treble quantity of dias-

tase the time is shortened, or a larger quantity of starch is converted in sugar.

With regard to the opinion that gravitation, electricity, &c., are examples of motion produced in one body by another which is at rest, we must consider, that a body at rest may pass into the state of motion in two essentially different ways.

How motion is produced.

1. By communication of the momentum of a body in motion, that is, by percussion, as of the hammer on the nail, the water on the wheel, or the wind on the sail.

By communication of momentum.

2. By the action of an attractive or repulsive force, which operates between the body to be moved and another body. Here the action is in all cases mutual, and the resulting velocities are inversely proportional to the masses set in motion.

By an attractive or repulsive force.

Since we must conceive chemical processes as phenomena of motion, it is, in the first place, not to be doubted, that all such processes as find an explanation in the formation of new products, belong to the second kind of phenomena of motion, since the attractive force of the elements, or chemical affinity, produces the resulting change of place and quality (that is, the motion) of the mattter affected. After the production of the compound the motion ceases, just as when a falling stone rests on the ground, or iron filings on the pole of a magnet.

Chemical process, as phenomena of motion, belong to the second class.

But when a body, which is itself in a state of decomposition, that is, whose particles are in a state of change of place, of motion, brings another body into a similar state, and observation has excluded all other known causes of change or decomposition in this second body, with the exception of *one*, when it is demonstrated that this one cause (communication of motion, friction, percussion, &c.) has a decided share in the formation and decomposition of a number of compounds, this last must be regarded as the efficient cause, if the ideas derived from the doctrine of motion are at all applicable to chemical phenomena. The demonstration of this last and only cause is therefore not a mere word, which has been substituted

Putrefaction and fermentation belong to the first kind of phenomena of motion.

for the expression, "catalytic force," but it is the expression of an idea, precisely the reverse of that of a catalytic force. From the proposition marked 2, it appears how erroneous the conclusion is, that gravitation, magnetism, &c., are examples of a body being set in motion by another which is at rest.

Gravitation, by itself, produces no motion.

A clock is kept in motion by the weight, but the clock does not wind itself up, and the heat of the sun has as much share in causing the motion of the mill-wheel as gravitation has. The water which drives the wheel was previously vapor, the vapor was previously liquid water. The water evaporates, the vapor, by loss of heat, becomes again liquid, and this liquid water falls by the action of gravitation, and continues to fall, like the weight in the clock, till a resistance destroys its motion.

Want of precision in expression a cause of erroneous conclusions and of misapprehension.

To the erroneous conclusions and modes of viewing phenomena, which depend on the method pursued, there is added, in many physiologists, a personal fault, which is explained by negligence and want of precision in expression. This fault is, that they represent things or phenomena, which they have observed by their senses, as deductions of their intellect, which, from habit, has this disadvantageous effect on the understanding, that at last they insist on seeing with their own eyes before they will admit them to be true, real conclusions, such as the deductions of an unknown value from two or more which are known, conclusions which from their nature cannot be rendered cognizable by the senses. This may probably explain how it happens that chemists frequently cannot convince many physicians of the simplest truths, after accumulating the most logical proofs.

Examples.

Examples of the truth of this remark may be found in every physiological work, and I shall here quote a few from one of the most recent. Valentin says (p. 6 of his Lehrbuch der Physiologie, Braunschweig, bei Vieweg, 1844), "We cut through the facial nerve, and observe that then the muscles of the face on the corresponding side are paralyzed as far as concerns the influence of the will. We *conclude* from this with justice," (we see from this,) "that by the facial nerve the effects of our will on the above-mentioned muscles of expression are produced."

"We find, after injuring the trunk or the ganglion of the tripartite nerve, secondary inflammation, suppuration, and even further destruction of the cornea, and we then *conclude*" (we have observed) "that to preserve the normal state of the eye, the integrity of that nerve is indispensable."

Again, p. 3.—"If I know, for example, that the coats of the arteries are elastic, then I may, without any thing further, *conclude* from this, that the arteries, as soon as they are rendered more full of blood, yield or expand to a certain degree, and, when the pressure is removed, return to their former volume" (that is, that they are elastic).

Points of contact between physiology and chemistry.

I have, in the preceding pages, pointed out in what manner a difference in the mode of viewing phenomena, and in the method of research, impedes a mutual understanding between physiologists and chemists, and shall now endeavor to specify more exactly the points in which physiology and chemistry must meet, in order to render to each other mutually profitable services.

Deviation of the laws which govern vital phenomena from chemical and mechanical laws.

When we endeavor to apply the notions derived from the knowledge of what are called the mechanical forces to the investigation of vital or chemical phenomena, we immediately perceive that the laws which govern the former deviate, in a number of relations, from those on which the peculiarities of chemical or vital combinations depend.

Relation of properties of the elements to those of the compound.

A chemical compound of two bodies possesses properties which are entirely different from those of its elements. The chemical force of the new body, its power to form new combinations or to effect decompositions, is not the sum of the chemical forces of its elements. From the properties of a muscular fibre we can draw no conclusion whatever as to those of carbon, hydrogen, nitrogen, and its other elements; and yet nothing can be more certain than that certain permanent relations exist between the properties of the elements and those of the compound.

Cinnabar is a metallic sulphuret, which has entirely different properties from lead glance and zinc blende. It cannot be doubted, that these differences depend on this, that in the first

mercury, in the second lead, and in the third zinc, is combined with sulphur; and that the properties of mercury, lead, and zinc must have a very decided and determinable share in the difference of the properties of the compounds; for the latter have obviously been determined by the former. We see this most distinctly in isomorphous substances. Sulphuret of lead is, in aspect, not to be distinguished from seleniueret of lead; ammoniacal alum from potash alum, seleniate of soda from sulphate of soda. The relations which exist between the chemical and physical properties of the elements have in many of these compounds remained constant; and in those in which a variation has taken place in color, solubility, &c., one property, namely, the physical form, has yet continued unaltered. The same or a similar relation is doubtless discoverable between the properties of all elements and those of their compounds; and all the efforts of chemists, as no one can deny, are directed to the discovery of such constant relations. This is the only way in which Chemistry can attain to natural laws, and in this way alone can Physiology, if she is to elevate herself to the position of a branch of natural philosophy, acquire a scientific foundation.

The chemical forces of the elements have a share in the vital properties.

It is certain that as yet we can deduce no physiological property from the laws or properties of the elements, but there can be no question that they are deducible from laws which begin to operate when these elements have assumed a certain arrangement. When the elements have combined to form an animal or vegetable substance, when they have acquired physiological or vital properties, the chemical forces which have given them their original properties are by no means annihilated or destroyed, any more than the cohesion of the particles of sulphur is annihilated when we melt a piece of sulphur. There has only been added another cause, (heat, for example,) which has destroyed the *result* of the cohesion (the solid form,) and does not allow us to perceive any longer the action of that force.

In vegetable and animal substances, the elements, as in other cases, obey mechanical and chemical laws, when the effect of these is not destroyed by opposing forces, which must be considered as the evidences of new laws, which govern the parts of an organizm.

If, therefore, by the co-operation of several causes, new laws, new phenomena are produced, which have no resemblance with the effects of the individual causes, considered separately, then the effects of the latter stand in a discoverable relation to the new phenomena, and it is these relations which must be sought for and determined. When we have learned these relations, then we shall be able to deduce, as in the case of isomorphous substances, without further observations, a multitude of unknown facts or phenomena.

The relations between chemical and vital effects must be ascertained.

That the property of the weight of the elements is constant in all chemical compounds; that, no matter in what way the elements may combine, the weight of the compound is equal to the sum of the weights of its elements: the attainment of this truth, of which hardly any one thinks that it has cost so much trouble and labor, has given to one part of Chemistry a purely scientific character. The knowledge of definite chemical proportions has enabled us to fix, *à priori*, all the possible compounds of a body, but could not, by itself, explain the apparent exceptions where bodies were found to be combined, not in definite, but in all possible proportions with one another. By attending to another property, namely, the relation between the external form and composition, not only has the explanation of these deviations become possible, but we have also acquired a much clearer notion of the causes of constant and definite proportions in general.

Relation between the weight of the elements and the chemical properties of compounds.

Progress in all branches of natural philosophy, in the physical sciences as well as in physiology, depends on the conviction that such laws of the mutually dependent relations in the properties of bodies, exist, and that they are discoverable.

Laws of mutual dependence in natural phenomena everywhere exist.

In the investigation of nature there is no other method of attaining a knowledge of the relations in which the properties of bodies mutually stand, than that we should first endeavor to become acquainted with these properties, and then study the cases in which they are altered. It is a natural law, admitting of no exceptions, that variations in one property are always and uniformly accompanied by changes, uniformly corresponding, in some other property; and it

Method of attaining a knowledge of the relations of dependence.

is perfectly obvious, that if we know the laws of these variations, we are placed in a position to deduce from one property, without further observation, the other. What we require is, knowing one thing, to predict the occurrence of another, and thus to deduce the unknown from the known.

Some examples may be sufficient to show the truth of these propositions.

Examples of laws of dependence.

It is known that every liquid, under the same conditions, boils at a fixed degree of temperature. This is so constant that we regard the boiling point as a characteristic property of liquids.

Pressure and boiling point.

One of the conditions of the constant temperature at which bubbles of vapor form in the interior of liquids, is external pressure. In all liquids the boiling point varies with this pressure, in each according to a peculiar law; it rises or falls as the pressure increases or diminishes. To each boiling temperature corresponds a certain pressure, to each pressure a certain temperature. It is well known that the knowledge of the law of mutual dependence between the boiling point of water and the pressure of the atmosphere has enabled us to ascertain by the thermometer our elevation above the level of the sea, that is, to measure one property by the variations of another.

Boiling point and composition.

The relations which exist between the boiling point of liquids and their composition are probably less known. Pyroxilic spirit, alcohol, and oil of potato spirit, are three fluids whose boiling points are very different. Pyroxilic spirit boils at 138·2°, alcohol at 172·4°, oil of potato spirit at 275°. The comparison of these three boiling points shows, that the boiling point of alcohol is 34·2° higher than that of pyroxilic spirit, $138{\cdot}2° + 34{\cdot}2° = 172{\cdot}4°$, and that the boiling point of oil of potato spirit is four times 34·2° higher than that of pyroxilic spirit, $138{\cdot}2° + 4 \times 34{\cdot}2° = 275°$.

Each of these three liquids, when oxidized under the same circumstances, yields an acid; from pyroxilic spirit is derived formic acid; from alcohol, acetic acid; from oil of potato spirit, valerianic acid. Each of these three acids again has its constant boiling point. Formic acid boils at 210·2°, acetic acid at 244·4°, valerianic acid at 347°. On comparing these three boiling points, it is at onco

perceived, that they bear to each other the very same relation as those of the liquids from which the acids are derived. The boiling point of acetic acid is higher than that of formic acid by 34·2°, and that of valerianic acid exceeds that of formic acid by four times 34·2°.

Here, as we perceive, a uniform variation in one property is attended by a uniform variation in another property. The former property is in this case the composition.

If we compare the composition of the six bodies, the three acids and the three liquids from which these acids are produced by the action of oxygen, we observe the following relations. The composition of pyroxilic spirit is represented by the formula $C_2H_4O_2$; that of alcohol by $C_4H_6O_2$, and that of oil of potato spirit by $C_{10}H_{12}O_2$. If we now represent by R a quantity of carbon and hydrogen corresponding to C H, that is, 1 eq. of each, then we at once perceive that the formula of alcohol is equal to that of pyroxilic spirit + 2 R.

$$\underset{\text{Pyroxilic Spirit.}}{C_2H_4O_2} + C_2H_2 = \underset{\text{Alcohol.}}{C_4H_6O_2}.$$

The formula of potato spirit may be expressed by that of pyroxilic spirit + 8 R.

$$\underset{\text{Pyroxilic Spirit.}}{C_2H_4O_2} + C_8H_8 = \underset{\text{Oil of Potato Spirit.}}{C_{10}H_{12}O_2}.$$

The formula of formic acid is $C_2H_2O_4$; that of acetic acid $C_4H_4O_4$; and that of valerianic acid $C_{10}H_{10}O_4$. It is easy to see that the formula of acetic acid is equal to that of formic acid + 2 R, and that the formula of valerianic acid is equal to that of formic acid + 8 R. According to these observations, the addition of 2 eq. carbon, and 2 eq. hydrogen, corresponds to an elevation of 34·2° in the boiling point. Now it may be shown that the relation of this group C_2H_2 to the boiling point, is constant, and that from a knowledge of the boiling point we may reason backwards to the composition. The boiling point of formiate of oxide of methyle is 96·8°, that of formiate of oxide of ethyle is 131°; the difference is 34·2°. From this we should be entitled to conclude that the latter contains, in its composition, C_2H_2 more than the former. This is, in fact, the case; for the formula of the formiate of oxide of methyle is $C_4H_4O_4$, and that of the formiate of oxide of ethyle is

$C_6H_6O_2$, or more by exactly C_2H_2. Butyric acid boils at 312·8°, exactly 3 times 34·2° higher than that of formic acid, 210·2°. A comparison of the formulæ of these acids shows, that butyric acid may be regarded as formic acid + 6 R, or C_6H_6. Toluidine and aniline are two organic bases, which differ in composition so far that aniline contains 2 R, or C_2H_2 more than toluidine. A comparison of their boiling points shows that aniline boils at a temperature 34·2° higher than the boiling point of toluidine.

The law of mutual connection is independent of the cause by which the phenomena are produced.

No one can hesitate to admit, in these examples, the existence of a natural law regulating the influence of this group (C_2H_2) on the boiling point, or can doubt that the qualities of a body bear a definite relation to its composition, and that to a variation in a quality, a uniform variation in something quantitative corresponds. It is worth while here to point out very particularly that the knowledge of this natural law is entirely independent of the proper cause, or of the conditions, which, when taken together, produce the constant boiling point; for what the boiling point in itself really is, this is as little known to us as is the true notion or definition of vitality.

The boiling point, composition, and specific gravity stand in a relation of mutual dependence.

In the above example, only one of the relations between the qualities of bodies and their composition has been pointed out; but of such relations there are, of course, just as many as there are of peculiar properties in bodies. A law has been discovered for an extensive group of organic chemical compounds, by which we can determine, from the knowledge of the boiling point and the composition, the weight of a cubic foot of the compound; and thus it appears, that the property of specific gravity, or the pressure which bodies of equal volume exert on that which supports them, stands in a perfectly definite relation to two other properties, and varies, exactly as these vary.

Specific heat and atomic weight.

A similar relation of dependence has been traced in regard to the amount of heat required by different bodies to raise their temperature to the same point, and the proportions by weight in which they combine. It is a well-known fact, that different bodies, at the same temperature, contain different amounts of heat. Equal weights of sulphur,

iron, and lead, heated to 212°, when placed in contact with ice, melt a certain quantity of it, and the quantities of liquid water, produced in these circumstances, are very different in the three cases. If the amount of heat in these three bodies were equal, the amount of ice melted must be equal in all; and the unequal effects here produced are sufficient to show the inequality of the efficient cause in the three cases. The sulphur melts six and a half times, the iron four times, as much ice as the lead. It is perfectly obvious that, if we had to heat equal weights of sulphur, iron, and lead, to the same extent, for example, from 60° to 400°, with the same spirit lamp, we should have to burn, for a certain weight of lead, 1 oz., for the same weight of sulphur. 6½ oz., and for the same weight of iron nearly 4 oz. of spirit. These different quantities of heat, required by equal weights of different bodies, in order to be heated to a certain extent, and which are peculiar to each, are called, precisely on this account, the peculiar or specific heats. From the knowledge of these unequal amounts of heat, which equal weights of these different bodies contain at the same temperature, a simple calculation by the rule of three enables us to ascertain the unequal weights of sulphur, iron, and lead, which contain the same amount of heat; and from such a calculation it appears that, for example, 16 parts of sulphur melt as much ice as 28 parts of iron and 104 of lead. But these numbers are the same which represent the combining proportions, or equivalents of these bodies. The equivalents of these and of many other bodies contain, or require, to heat them to the same extent, equal quantities of heat; and if we suppose the equivalents to represent the relative weights of the atoms, it is plain that the amount of heat, which each atom takes up or gives out under the same conditions, is equal for each single atom, and, when expressed in numbers, is, for equal weights, inversely proportional to the weights of the atoms. It is truly a surprising result, that the quantity of ice which a body melts, has served in many cases to correct and determine the proportions by weight in which this body combines with others.

Specific heat and musical tone in gases.

But it may appear, to many persons, yet more wonderful, that this property (the taking up or giving out of heat) should stand, in gaseous bodies, in a perfectly

definite relation to the tone of a pipe or flute, produced by forcing the gas through the instrument; so much so, that a celebrated philosopher (Dulong) was able to fix, relatively, from the difference of tone, the amount of heat which equal volumes of the gases give out when compressed, or absorb when they expand. In order clearly to comprehend this remarkable relation, we must call to mind one of the finest thoughts of La Place in reference to the relation between the specific heat of the gases and their power of propagating sound. It is known that Newton, and many subsequent mathematicians, sought in vain to establish a formula, corresponding to observation, for the velocity of sound. The calculated result approached to that of observation, but there was invariably a difference which could not be explained. Now since the propagation of sound is effected by the vibration of the elastic particles of air, and, therefore, in consequence of a compression, followed by an expansion, of these particles, and since by the compression of air heat is set free, and by its subsequent expansion heat is absorbed, La Place suspected, that these phenomena of the liberation and absorption of heat, must have an influence on the propagation of sound, and it appeared, in fact, that after taking into account the specific heat of air, the formula of the mathematicians became free from all error, and supplied an exact expression for the observed velocity.

If we now calculate the velocity of sound by Newton's formula (that is without reference to the specific heat of air), and compare the result with that obtained by the formula of La Place, a difference is perceived between them in the length of the space over which a wave of sound moves during a second. This difference depends on the specific heat of the air, that is, on the amount of heat liberated from the particles of air, set in motion by the propagation of sound. Now it is clear, that this difference in the velocity of sound, according to the two formulæ, will be found greater or smaller in other gases, which for equal volumes, contain and give out, on compression, more or less heat than air; and thus it is easy to see, how the numbers which express this unequal velocity of propagation of sound, in different gases, become at the same time an expression for the unequal quantities of heat, which they contain.

Now, since the acutenes or gravity of a tone depends on the number of vibrations of the wave of sound in a second, and, consequently, on the velocity with which the motion is propagated (for we know that in all gases the velocity of propagation* of a wave of sound is directly proportional to the number of vibrations in the tones produced by it), we can thus explain, how, by the different pitch of the tone, produced in different gases by the same pipe, the specific heat of these gases (or the difference in the amount of heat they contain) may be ascertained. The great discovery that musical harmony, and every sound which stirs the heart, and attunes to joy, or inspires with valor, is the sign of a definite and discoverable number of undulations of the particles of the propagating medium, and consequently a sign of every thing deducible from this motion by the laws of the undulatory doctrine, has raised acoustics to the rank which that science at present occupies. A number of truths, bearing on the nature of musical tones were deducible from that doctrine, while other truths, empirically obtained, led to a corresponding acquaintance with the properties of vibrating bodies previously quite unknown.

It is said of a celebrated violin maker of Vienna, that he was in the habit of employing the hammer in selecting wood out of the forests for his instruments, choosing only such trees as when struck gave forth a certain sound, known to him alone. This is certainly fabulous, but not the slightest doubt can be entertained, that he knew that the upper and under board of a good violin make a certain number of vibrations in a second and yield a certain tone, and that their thickness must be regulated accordingly.

Electricity and magnetism, magnetism and heat, magnetism and chemical force.

When, finally, we reflect that the current of electricity passing through a wire stands in a perfectly definite relation to the magnetic properties which the wire thereby acquires; when we bear in mind that by means of the magnetic needle the slightest variations of radiant heat may be measured; that the amount of electricity set in motion may be expressed in numbers, by the help of the same needle, that it may also be measured in cubic inches of hydrogen gas, and in weights of metals; when we therefore see

* The velocity of propagation is the product of the number of undulations in a second, into the length of a wave.

that the causes or forces on which depend the properties of bodies, their power of making an impression on our senses, and, in general, of producing any effect, bear to each other a discoverable relation of dependence, who can, in the present day, entertain a doubt, that the vital properties of bodies, like all other properties, follow these laws of dependence, or that the chemical and physical properties of the elements, their form and arrangement, play a definite and discoverable part, in the phenomena of vitality?

Vital properties are not exceptions to a law of nature.

It is their method of investigation which has led many physiologists and pathologists to regard the vital properties in some measure as exceptions to a great law of nature. How else can it be explained, that they do not consider the number and grouping of the elements of which the organic tissues are composed, as a physiological property, which must serve as an altogether indispensable means of acquiring a knowledge of the vital phenomena? How can it be explained that they do not take into account, in curing and removing diseased conditions, the elementary composition of their remedies, and the properties thereon depending, by which their effects are produced? A mere knowledge of formulæ is evidently not sufficient, but it is absolutely necessary to discover the laws which regulate the relations of the composition and form of the food or of the secreta to the nutritive process, and of the composition of remedies to the effects which they produce on the organism.

Anatomy above all things necessary.

It is certain, that the whole progress of vegetable and animal physiology, from the time of Aristotle till our times, has only been rendered possible by the advance of anatomy. As he, who has seen no more of distillation than the mash-tub, the fire, and the pipe from which the spirit trickles, will remain ignorant of the process, so, in all cases, without a knowledge of the whole apparatus, insight into the process is impossible. But the organism is a much more complex apparatus, which, above all things, demands a perfectly accurate knowledge of the structure of all the individual parts, before we can appreciate their significance and the function they fulfil in relation to the whole. (Schleiden.)

But we must not forget, that from the time of Aristotle to that of Leuwenhoek, Anatomy, taken by itself, has shed only a partial

light over the laws of the vital phenomena, that a knowledge of the apparatus of distillation alone does not teach us its object, that the same may be affirmed of many organic processes, as of distillation, in which he who knows the nature of fire, the laws of the distribution of heat, the laws of vaporization, the composition of the mash, and that of the products of the distillation, understands infinitely more of that process, not only than he who is acquainted with the minutest parts of the apparatus, but also infinitely more than the workman who has fashioned that apparatus.

With every new discovery in anatomy, the descriptions of parts have improved in precision, accuracy, and comprehensiveness: indefatigable research has at last reached the cell; and from this elevation a new kind of research must take its rise.

Anatomy alone is not sufficient.

But if, as many persons suppose, now, and in future, the further progress of physiology is dependent only on the perfecting of our knowledge of the anatomical formation and structure of organisms, then chemistry, inasmuch as anatomical knowledge cannot be increased by its means, will in no way serve to promote physiology; for the problem of chemistry is not to discover the form, but to determine the relation between the form and the elements, with their arrangement, by which that form is produced.

By the knowledge of anatomical formation, and of the relations of structure, anatomy alone is promoted, and with the minutest research into the phenomena of motion in the body, we can learn nothing of the causes or laws which regulate them; it is only the mode of direction of this motion, with which we thus become acquainted.

What must be added.

If anatomical knowledge is to serve for the resolution of a physiological question, then, of necessity, something more must be called in, and the most obvious is the matter of which the organized form consists, the forces and properties which belong to it, in addition to the vital properties, and a knowledge of the origin of this matter, and of the changes which it undergoes in order to acquire vital properties. Finally, it is indispensable to know the relations in which all the constituents of the organism, the fluid as well as the solid, altogether independently of the form, stand to each other. To many physiologists, chem-

istry alone appears to have been enriched by all which chemistry has discovered, with reference to these highly important questions, although in chemistry, all these results occupy a rank quite as subordinate as that attained by the analyses of minerals and of mineral waters.

Chemistry alone not sufficient.

Another fundamental error, committed by other physiologists, is this, that they suppose the chemical and physical forces alone, or in combination with anatomy, sufficient to explain the phenomena of vitality. It is indeed difficult to understand, how the chemist, intimately acquainted with chemical forces, recognizes in the living body the existence of new laws, of new causes, while the physiologist, little or not at all familiar with the knowledge of the action and nature of chemical and physical forces, is ready to explain the same processes, with the aid of the laws of inorganic nature alone.

The last-mentioned view is, in reality, the extreme consequence of a reaction against a previous one. In the age, not yet long past, of metaphysical physiology, every thing was explained by the vital force. The reaction rejects the vital force, and believes in the possibility of reducing all vital processes to physical and chemical causes. "In the living body prevail," thus men spoke forty years ago, "other laws than those of inorganic nature." Many physiologists of the present day, on the other hand, regard them as of the same kind. That which, in both views, is profitless for us, is that, neither formerly nor at this time, have men endeavored to determine or discover the differences in the effects of the vital force, and those of the inorganic forces, and their likeness or unlikeness. The conclusions arrived at were not founded on a knowledge of the likeness or unlikeness of their mutual relations, but on ignorance of these things.

What is the meaning of chemical forces.

The same physiologists, who regard the vital processes as the effects of inorganic forces alone, forget entirely, that by the expression, "chemical forces" is meant nothing else than the *quantitative* in the different vital phenomena, and the *qualities* determined by these quantities. From the false notion which has been formed of the influence of chemistry on the explanation of the vital phenomena, it has happened, that on the one hand, this influence has been estimated too low,

and that, on the other, the expectations and demands on it have been raised too high.

No relation can be formed by numbers.

When a definite connection between two facts exists, or is discovered, it is not at all the problem of chemistry to demonstrate this connection, but merely to express it in quantities or numbers. By numbers alone, a relation between two facts cannot be produced, if this relation do not really exist.

Numbers merely express existing relations.

Oil of bitter almonds and benzoic acid are, in reference to their occurrence and their properties, two entirely different organic compounds. Only a few years ago there was no idea of a mutual relation between them. It was then discovered, that oil of bitter almonds, in the air, became solid and crystalline, and that the body thus produced was identical in properties and composition with benzoic acid. After this it was impossible to overlook the existence of a relation between them. Observation showed that during the conversion of oil of bitter almonds into benzoic acid, oxygen is absorbed from the air, and the analysis of both expressed in numbers the change which had taken place, and thereby explained it, as far as it could be explained.

Examples.

In like manner, by studying the changes which oil of potato spirit undergoes when acted on by oxygen, a definite relation was discovered between that body and valerianic acid, and it was shown by the numerical expression, that they are related to each other as alcohol and acetic acid are.

Mutual chemical relations of urea, uric acid, allantoine, and oxalic acid.

Human urine contains urea, and frequently uric acid; in the urine of certain classes of animals, the uric acid, in that of others the urea, is wanting. When the quantity of uric acid increases, the proportion of urea in the urine diminishes; the urine of the fetal ox contains allantoine, and in human urine oxalic acid is an ingredient rarely absent. A variation in certain vital processes of the organism is accompanied by a corresponding change in the nature, quantity, and quality of the compounds secreted by the kidneys, It is the problem to be solved by the chemist, to express, quantitatively, the observed relations in which these bodies stand to each other, and to the processes of the organism.

How chemistry proceeds in order to express these relations.

By means of analysis, chemistry first gives to the words urea, uric acid, allantoine, and oxalic acid, their quantitative significance. By these formulæ no mutual relations between these bodies are established, but inasmuch as chemistry studies their characters, and the changes which these compounds undergo under the influence of oxygen and of water, that is, of those bodies which have a share in their formation, or alteration in the organism, we attain to expressions of a definite and unmistakable relation between them. By the addition of oxygen, uric acid is resolved into three products, allantoine, urea, and oxalic acid. By a greater addition of oxygen, uric acid is at once resolved into urea and carbonic acid. Allantoine presents the composition of a urate of urea. A comparison of the conditions, discovered by the chemist, under which uric acid is converted into urea, with those which accompany the process in the organism, leads to the conclusion, that the conditions (in this case a supply of oxygen) are the same in the two cases, or that they differ. These differences supply new starting-points for investigation, and when these are cleared up, the process in the organism is explained.

Urea and uric acid are products of the changes which the nitrogenized constituents of the blood undergo under the influence of water and of oxygen; the nitrogenized constituents of the blood are identical in composition with the nitrogenized constituents of the food. The relation of the latter to uric acid and urea, and of all these bodies to the oxygen of the air and the elements of water, the quantitative conditions of the formation of these products, all these things chemistry expresses in formulæ, and thereby explains them, as far as her province extends.

Meaning of chemical formulæ.

It is plain even to one not conversant with the subject, that a difference in the properties of two substances is dependent either on a different arrangement of the elements, or on a quantitative difference in their composition. The formulæ of the chemists are expressions of the different arrangement, or of the quantitative differences, which accompany the qualitative differences. Modern chemistry, even by the most careful analysis, cannot determine with certainty the composition of an organic body, unless its quantitative relation to

another body, the formula of which is not doubtful, be ascertained. It was only thus, that, for example, the formula of oil of bitter almonds could be determined; and when a relation between two bodies cannot be ascertained by simple observation, then the chemist is compelled to create such relations by his art. He endeavors to resolve the body into two or more products, he examines those products which he obtains from it by the influence of oxygen, or of chlorine, of alkalies, or of acids, and by these means he at last succeeds in obtaining one or more products whose composition is fully ascertained, whose formulæ he knows. With the formulæ of these products, he now connects the formula of the body under investigation. The sum of all he deduces by the aid of the knowledge of one, of several, or of all the parts of which that whole consists. Thus the absolute number of equivalents of carbon, hydrogen and oxygen, in a particle of sugar cannot be determined by analysis. The dexterity of a chemist gives no security for the accuracy of his analysis of salicine or of amygdaline. But sugar combines with oxide of lead, and is resolved, by fermentation, into alcohol and carbonic acid, two compounds, the formulæ of which are exactly known; amygdaline is resolved into hydrocyanic acid, oil of bitter almonds, and sugar, and salicine into sugar and saligenine.

Value of formulæ.

It is plain that if the weight of the body and that of one, or two, or all the products derived from it, as well as their formulæ, are known, then the number and proportion of one, or two, or all of its elements, that is, its formula, may be deduced, and the result of analysis may thereby be confirmed or corrected.

Why the chemist studies the products of decomposition of substances.

The true significance of the formulæ of the chemist is therefore evident. The true formula of a body expresses the quantitative relation in which it stands to one, two, or more other bodies. The formula of sugar expresses the total sum of its elements, which unites with an equivalent of oxide of lead, or the quantity of carbonic acid and alcohol into which it is resolved by fermentation. We can consequently understand why the chemist is forced to resolve into numerous products the body whose composition he wishes to determine, and why he studies its compounds with other bodies.

All these things are controls for his analysis. No formula deserves entire confidence, if the body whose composition it is meant to express, has not been subjected to these operations.

Some modern physiologists, forgetting that the knowledge of the relations of two phenomena ought to precede their numerical expression, have made chemical formulæ, in their hands, into a mere play of numbers, destitute of meaning. Instead of an expression for a really existing relation, they have sought, by means of numbers, to establish relations which in nature do not exist or have never been observed. But this property does not belong to numbers.* The time, however, will come, although the present generation will hardly live to see it, when we shall have obtained a numerical expression, in the shape of chemical formulæ, for all the normal processes or powers of the organism, when we shall measure the variations in the functions of its individual parts by corresponding variations in the composition of the matter of which these parts consist, or of the products which that matter yields; when the effects produced by morbific causes or by remedies shall be quantitatively determined; when a better method shall bring

* "Microscopic anatomy shows, that in the brain and spinal chord a mixture of gray and white substance exists, and that in this organ albumen and oil are associated together. But instead of availing themselves in their researches of this anatomical fact, chemists analyzed the brain as a whole, that is, they analyzed an unknown and probably variable mixture of albumen and fat. In this way they discovered a peculiar fatty acid, supposed to contain nitrogen, the cerebric acid, and endeavored to support on theoretical grounds the anomaly of a nitrogenized fatty acid, by theoretical arguments. But by a chemical deduction, in which the formula of Mulder for Proteine is employed, it may be shown that they had in their hands nothing else than might have been expected, considering the matter from the anatomical point of view, namely, a mixture of albumen, fat, and phosphorus. For

$$\text{1 Atom Cerebric Acid} \ldots\ldots\ldots\ldots = P\,C_{178}\,H_{340}\,N_5\,O_{38}$$

$$= \left\{\begin{array}{lll} \tfrac{1}{2}\text{ Atom Proteine} & = & C_{20}\,H_{31}\,N_5\,O_6 \\ \text{14·3636 At. Fat} & = & C_{158}\,H_{273}\quad O_{14\cdot3636} \\ \text{18 At. Water} & = & \quad H_{36}\quad O_{18} \\ \text{1 At. Phosphorus} & = & P \end{array}\right.$$

$$\overline{P\,C_{178}\,H_{340}\,N_5\,O_{38\cdot3636}}$$

"But in this way the apparent anomaly which the substance of the brain would otherwise present, is brought again under the rule." (Valentin, in his Lehrbuch, i. 174.)

us a knowledge of all the conditions of the vital phenomena, and shall introduce clearness and certainty into our explanations. Men will then look upon it as incomprehensible that there ever was a time when the share which chemistry is destined to take in these conquests of science was contested, or when doubts could be entertained concerning the mode in which her aid was to be given to physiology.